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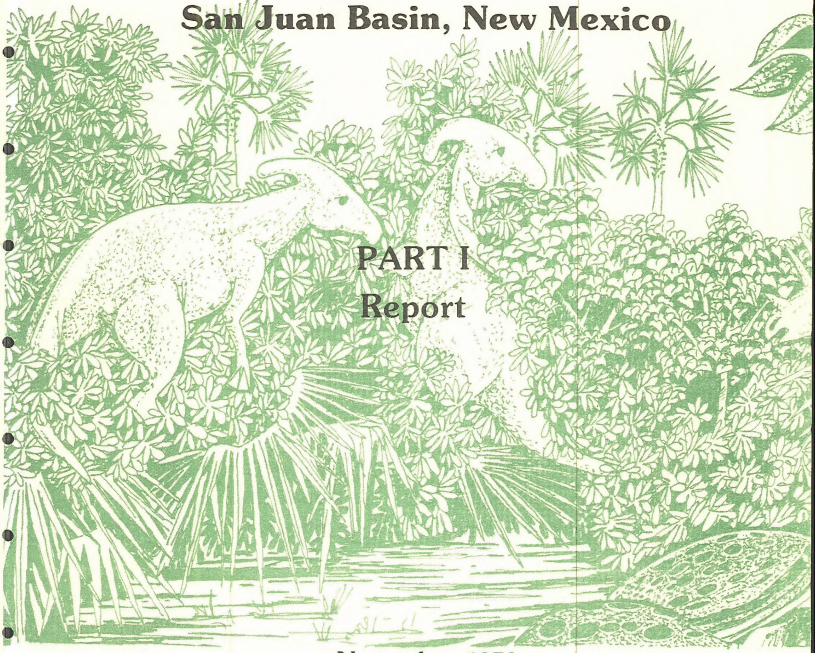

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Report

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A STUDY TO DETERMINE PALEONTOLOGICAL MITIGATION FOR COAL LANDS IN THE SAN JUAN BASIN, NEW MEXICO

November 1979

W. E. Miller

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Bureau of Land Management
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ABSTRACT

The San Juan Basin is a structural basin in northern New Mexico and southern Colorado covering an area of approximately 7500 square miles. Within Upper Cretaceous and Lower Tertiary rocks of this basin are major deposits of both high quality coal as well as continental and lacustrine fossils.

The present study focuses on mitigation procedures which will allow the recovery of both coal and fossils. It is our recommendation that a major salvage effort precede coal mining operations. Methods were tested which would also permit the recovery of fossils uncovered in mining operations and still retain efficient means of coal recovery.

We recommend a paleontological monitoring specialist be hired by the supervisory government agency to work cooperatively with mining companies to identify and plan efficient methods of fossil recovery during continued mining operations.

Emphasis is placed on the need for cooperation between the mining industry, government and academic institutions to assure the recovery of the abundant record of life which lived in the San Juan Basin during Late Cretaceous and Early Tertiary time. It was our experience during this year of study that employees of these institutions were uniformly anxious to cooperate in mitigating efforts to recover valuable fossils from the basin. It is also our opinion that a paleontological monitoring specialist, through an informal, but deliberate, education program, could gain support for mitigation efforts from a host of mine personnel whose everyday work assignments put them in a position to make valuable and exciting discoveries of fossils.

The potential value of both coal and fossil resources are of significant magnitude to justify a major effort on the part of all parties concerned.

INTRODUCTION

Study Goals

The San Juan Basin of New Mexico contains one of this nation's major coal reserves, with only a relatively small amount of the total deposit having been mined to date. With the present energy needs, however, more extensive coal mining is anticipated in the very near future. In the strata that yield the coal and those immediately overlying them are numerous fossils of significant scientific value. Therefore, a serious problem presents itself. How can the coal be removed with minimal adverse impact on existing fossils? The Bureau of Land Management, recognizing this problem, has contracted the present study in an attempt to determine what mitigating techniques might be employed to preserve as many scientifically valuable fossils as possible. The goals as set forth by the Bureau of Land Management are as follows:

1. Prove the salvageability of various fossil materials in areas of direct impact.
2. Estimate the cost of techniques used.
3. Prove the feasibility of mitigation for anticipated indirect impacts.
4. Estimate the cost of the indirect impact mitigation.

The areas of primary concern were stated as the Kirtland and Fruitland Formations in the Bisti Badlands.

A copy of the letter sent by the Bureau of Land Management Office in Albuquerque which establishes the above goals and their priorities is attached in an appendix.

METHODS

The study contracted by the Bureau of Land Management for paleontological mitigation in the coal and fossil rich San Juan Basin is without precedent; not because of a particular uniqueness to the area, for other coal rich areas are also natural repositories of great fossil accumulations, but rather because of the circumstance of timing in this area. Presently the basin is relatively untouched. The greatest coal mining operations are yet to be developed, and the fossil resources are relatively unstudied compared with the potential, following the massive, widespread exploration associated with new coal mining. If a pattern of cooperation between mining and academic interests can be established and maintained, the rewards to both groups will be monumental.

Our study of this problem started in the Fall of 1978. Initial efforts were concentrated on the compilation of the annotated bibliography whose completion was not achieved until early Fall 1979. In the Spring of 1979, the writers toured the basin south of Farmington, New Mexico, with Drs. J. K. Rigby Jr. and Barry Kues describing the stratigraphic sequence and pointing out sites for future collecting. Emphasis during this three day excursion was on Cretaceous and Lower Tertiary units.

We further expanded our understanding of the area by visiting all active coal mining operations in the San Juan Basin. These included the San Juan Mine (Western Coal Co.) and Navajo Mine (Utah Interntational), Farmington, New Mexico; McKinley, Carbon, and Amcoal mines near Gallup, New Mexico and Kaiser Steel's York Canyon Mine near Raton, New Mexico. For additional study of underground coal mines, we inspected U.S. Steel's mine in East Carbon City, Utah.

In every mine we were extended utmost cooperation. Mine officers and miners were anxious and willing to share their experience and offer suggestions. Without exception, mine personnel were only casually familiar with fossils. Many workers reported never seeing fossils in their many years of mining. Others were familiar with occasional discoveries in the course of their mining experiences. All expressed interest and willingness to pay greater attention to fossils as they encountered them in the mine operations and were sympathetic to the goals of our study.

Permits were granted by the Bureau of Land Management for collection of representative fossil occurrences. Vertebrates, plants and invertebrates were collected from a variety of sites in Cretaceous and Lower Tertiary rocks. Records were kept of time and cost estimates during the collecting of various fossil types. These collections have subsequently been, or are being, curated and identified, at least, to the generic level.

Study of current area surface and underground mines, as well as the nature of fossil occurrences in the coal bearing and overlying strata, formed the basis of our model for paleontological mitigation procedures. The model was formulated and tested at Western Coal's San Juan Mine.

ACKNOWLEDGEMENTS

Throughout this study, the writers have sought experienced people in the mining industry, government agencies related to mining, paleontologists, and geologists. The help gained from these people is gratefully acknowledged. Numerous people have shared their wisdom based on many years of experience. The following people were especially helpful and cooperative in their efforts to support the study: Mr. J. Balmer, Mine Superintendent of the San Juan Mine, Utah International, Mr. Sterling Grogan, Environmental Engineer, Utah International's Navajo Mine, Farmington, New Mexico; Drs. Steven Hook, Donald Wolberg, and Frank Kottlowski New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico; Mr. Paul Watson, General Superintendent, Mr. Robert Pobrick, Mine Superintendent, and Mr. Carl Winters, Mine Engineer, U.S. Steel East Carbon City, Utah; Mr. Robert West, General Superintendent and Mr. Donald Murray, Mine Superintendent, Amcoal, Gallup, New Mexico; Mr. Jerry Tystad, Chief Mining Engineer and Mr. Dave Banazak, Geologist, Carbon Coal Co., Gallup, New Mexico. Mr. John Wilson and Mr. Clark Mosley, P. & M. McKinley Coal Mine, Gallup, New Mexico; Mr. Dave Wingo, Mine Engineer, and Mr. Steve Starkovich, Mine Superintendent, Kaiser Steel York Canyon Mine, Raton, New Mexico. Mr. Rick Usery, Western Coal Company, San Juan Mine, Farmington, deserves singular acknowledgement for his unusual cooperation, helpfulness and wisdom throughout all phases of the study. Mr. George Byers, Environmental Engineer, Western Coal San Juan Mine offered useful suggestions. Drs. Barry Kues, University of New Mexico, Earle G. Kauffman, U.S. National Museum, Washington, D.C., Lee Parker, California Polytechnic State University, San Luis Obispo, William Clemens and J. Howard Hutchison, University of California at Berkeley, California, and Dennis Bramble of the University of Utah, Salt Lake City collaborated on fossil identification.

Mr. Tim Rowe of the Museum of Northern Arizona at Flagstaff provided pertinent data relating to that Museum's collection of dinosaur material from the San Juan Basin.

To each of these people we extend thanks. The writers, however, accept full responsibility for the context and recommendations of this report.

GEOLOGY

Introduction

The San Juan Basin of northwestern New Mexico and southwestern Colorado includes parts of San Juan, McKinley, Sandoval and Rio Arriba Counties of New Mexico, and parts of Archuleta and La Plata Counties of Colorado.

Within the outcrop belt of the Late Cretaceous, Pictured Cliffs Sandstone, the San Juan Basin forms an approximately circular structure 100 miles in diameter. The total area of this basin approaches 7500 square miles (Fig. 1). Rocks within the basin range in age from Precambrian to Recent totaling at least 15,000 feet in thickness. Upper Cretaceous rocks, more than 6000 feet thick, preserve a local record of the widespread epicontinental seaway which covered the middle part of the entire North American continent during Late Cretaceous time (Fig. 2).

Upper Cretaceous rocks record three major, as well as several minor, basin-wide cycles of transgression and regression of the epeiric seaway (Figs. 3,4). As the seaway gradually receded eastward, continental deposition followed with coal forming swamp conditions at its leading margin. Mineable coal deposits occur in three Late Cretaceous formations; the Fruitland, Crevasse Canyon and Menefee. The Fruitland Formation alone is estimated to contain 200 billion tons of coal in beds two or more feet thick (Fassett and Hinds, p. 1971, p. 67). The coal bearing Fruitland beds outcrop around the basin, with the broadest outcropping on the north and west flanks. Elsewhere it is covered by as much as 8000 feet of overburden (Fig. 5).

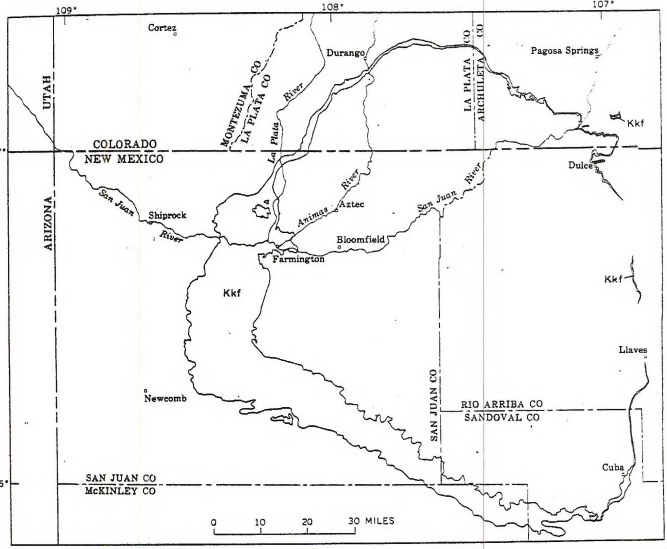


Figure 1. Map showing location of the San Juan Basin, Kkf, Fruitland Formation and Kirtland Shale (from Fassett and Hinds, 1971, p. 2).

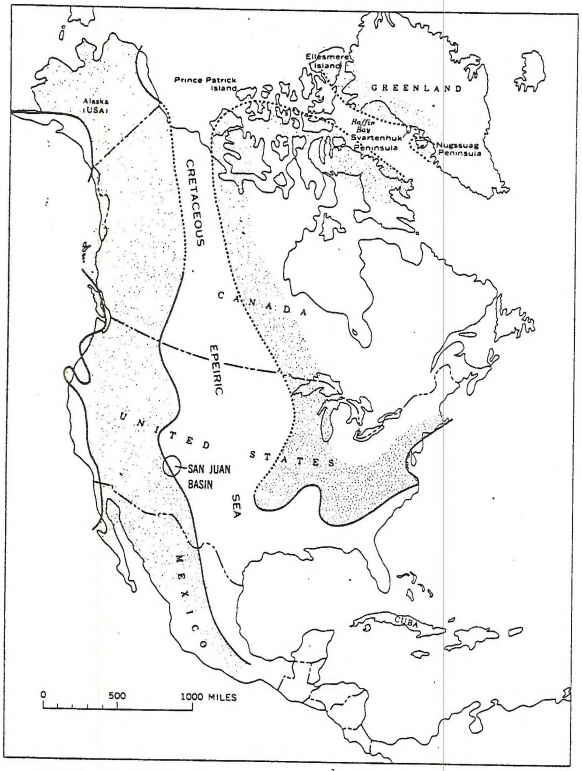


Figure 2. Map of North America during Cretaceous time showing approximate distribution of land and sea. Location of San Juan Basin is indicated (from Fassett and Hinds, 1971, p. 10).

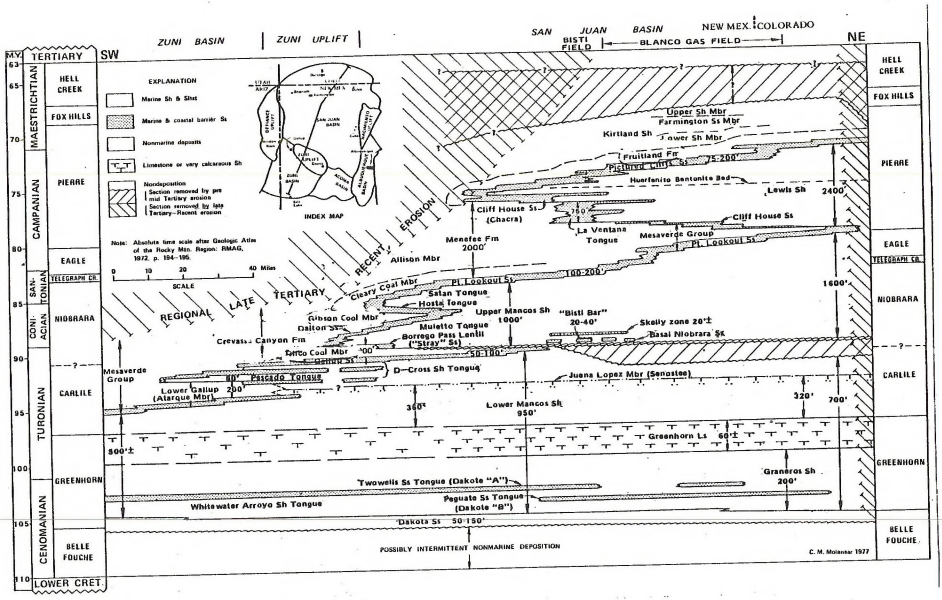


Figure 3. Chart showing Upper Cretaceous stratigraphic nomenclature in use in the San Juan Basin and adjacent areas (from Molenaar, 1977, p. 160). Note three basin-wide episodes of marine transgression and regression.

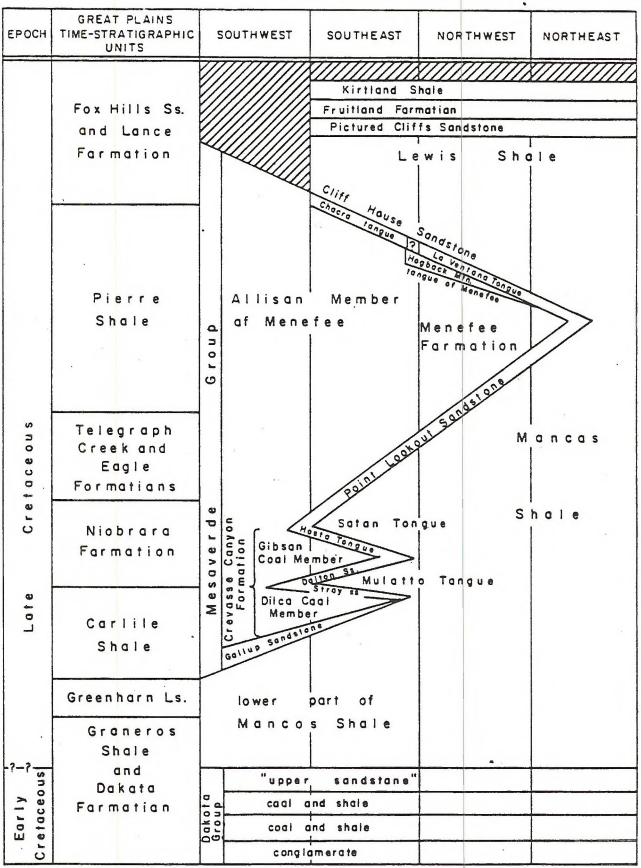


Figure 4. Stratigraphic nomenclature in use in San Juan Basin and Great Plains (from Shoemaker and Whyte, 1977, p. 9).

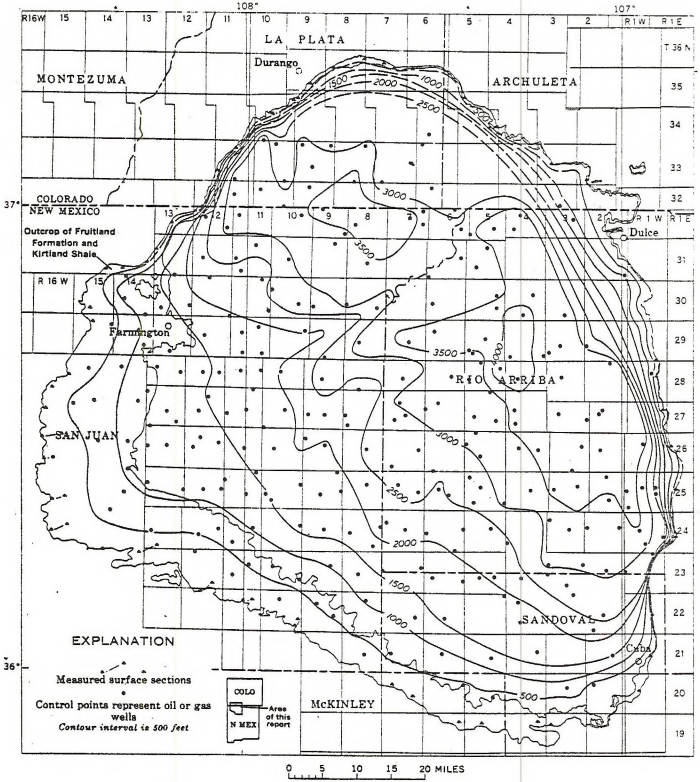


Figure 5. Isopach map showing average thickness of overburden on Fruitland Formation coal deposits (from Fassett and Hinds, 1971, p. 66).

Of major interest to this study are the Upper Cretaceous strata composed of intertongueing marine and nonmarine units. The final regression of the epeiric sea is marked by the deposition of the Late Cretaceous Pictured Cliffs Sandstone. Directly overlying the Pictured Cliffs Sandstone is the coal-bearing Fruitland Formation containing abundant fossil remains of vertebrates, plants and, to a lesser extent, occurrences of bivalves and gastropods.

Geologic Setting

The San Juan Basin, a Late Cretaceous Laramide structure, contains rocks of the Cambrian, Devonian, Mississippian, Pennsylvanian, Permian, Triassic, Jurassic, Cretaceous, Tertiary and Quaternary systems. Precambrian rocks were penetrated at a depth of 14,030 feet in a well drilled by El Paso Natural Gas Company (Sec. 7, T29N, R5W) (Fassett and Hinds, 1971, p. 4).

Structurally the basin is strongly asymmetric with a steep northern limb, clearly demonstrated by Hogback Monocline near Farmington, New Mexico, and a gently dipping southern limb (Fig. 6,7).

Surrounding the basin and forming its outer margin are the San Juan Uplift, Gallina-Archuleta Arch, Nacimiento Uplift, Puerco Platform, Zuni Uplift, Defiance Uplift and Four Corners Platform. Structural relief between the basin and the Gallina-Archuleta arch is at least 3,000 feet (Woodward and Callender, 1977, p. 210).

Stratigraphy

Upper Cretaceous Rocks

Mesa Verde Group

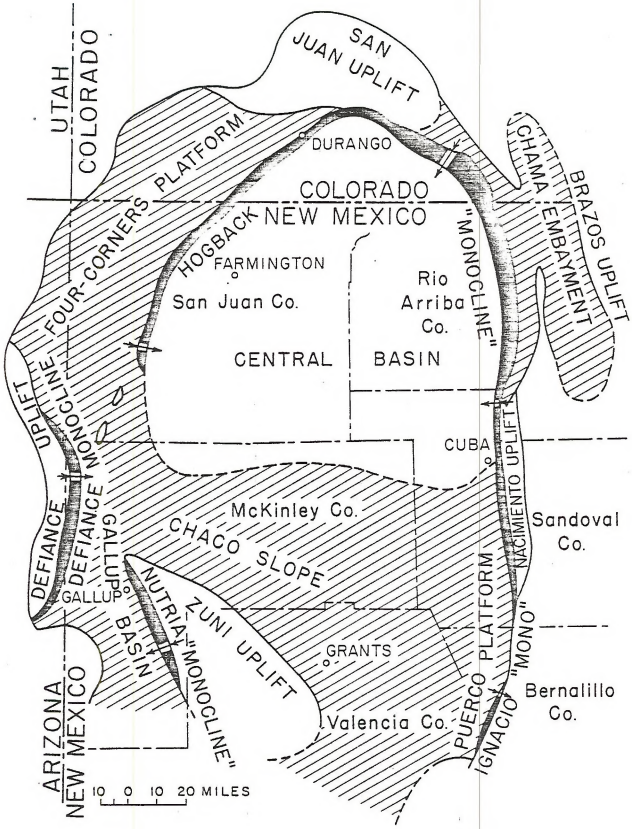


Figure 6. Structural elements of San Juan Basin (from Beaumont et al., 1976, p. iv, after Kelley, 1951, p. 125).

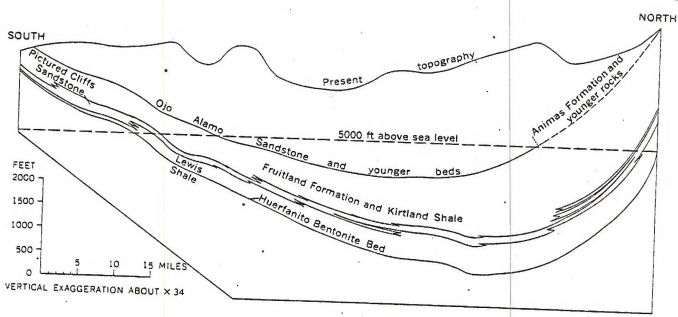


Figure 7. Diagrammatic cross-section showing present structure and topography of the basin, datum is mean sea level (from Fassett and Hinds, 1971, p. 40).

At the type locality in southwestern Colorado, the Mesa Verde group includes: the Point Lookout Sandstone, Menefee Formation and Cliff House Sandstone. In the southern part of the San Juan Basin, the Mesa Verde Group includes the Gallup Sandstone and overlying rocks which are mostly nonmarine. The Cliff House Sandstone is the recognized top of the Mesa Verde throughout the basin.

Gallup Sandstone

This unit records the first major regressive phase of the cyclic deposition in the San Juan Basin during the Late Cretaceous. The coarse coastal marine sandstone varies from a pinchout at its eastern extremity to 300 feet maximum thickness along the flanks of the Zuni and Defiance Uplifts. In terms of direct impact due to coal strip mining, the Gallup is the floor below which rocks will not be disturbed.

Crevasse Canyon Formation

As a nonmarine deposit above the marine Gallup Sandstone, the Crevasse Canyon Formation contains in ascending order the Dilco Coal, Dalton Sandstone, Bartlett Barren, and Gibson Coal Members. The Dilco Coal, approximately 300 feet thick, is not being mined presently. The Gibson Coal Member, 150 feet thick including the Cleary Coal Member of the Menefee Formation, is currently being mined (Wilson, 1977, p. 254). The Dalton Sandstone is a regressive coastal-barrier sandstone (Molenaar, 1977, p. 162) and the Bartlett Barren Member is about 375 feet thick.

Point Lookout Sandstone

The Point Lookout Sandstone is an extensive coastal-barrier sandstone which records a regression within the basin. This formation is correlated among others to the Star Point Sandstone in the Wasatch Plateau (Molenaar, 1977, p. 164). The Point Lookout, like other regressive-transgressive sand bodies in the basin, pinches out seaward or northeast. Maximum thickness according to Molenaar (1977, p. 160) is 200 feet.

Menefee Formation

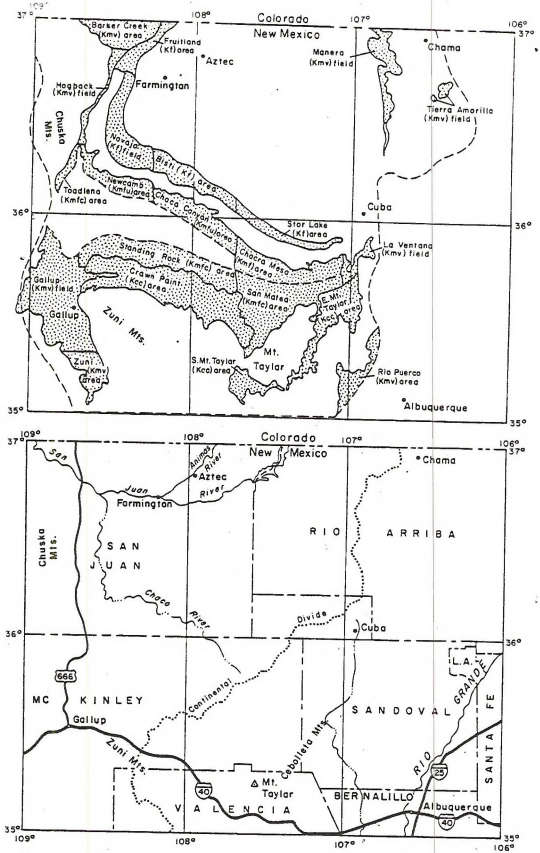
This unit consists of nonmarine-paludal to alluvial-plain carbonaceous shales, fluvial sandstones, flood plain shale and coal. The coal bearing Menefee ranges from a pinchout in the north to 2200 feet in the southern part of the San Juan Basin according to Molenaar (1977, p. xii, Fig. 8).

Cliff House Sandstone

This thick sandstone unit was deposited in a transgressive cycle of marine encursion across the San Juan Basin which included some minor regressive episodes as well. The Cliff House varies from a pinchout to a maximum of 800 feet within the La Ventana Tongue (Molenaar, 1977, p. 164).

Lewis Shale

Recording a major marine transgression, the Lewis Shale resembles the older Mancos Shale below the Mesa Verde. Bentonite beds, representing ancient volcanic ash falls within the marine shale record excellent time markers in subsurface correlations within the basin. The thickest of the bentonites, the Huerfanito Bentonite Bed of Fassett and Hinds (1971, p. 6) is up to 12 feet thick. The Lewis varies in thickness from a pinchout to about 2400 feet (Fassett and Hinds, 1971, p. 6).



Kcc—Crevasse Canyon Formation
Kd—Dakota Formation
Kf—Fruitland Formation
Kmf—Menefee Formation
Kmfc—Cleary Coal Member of Menefee Formation
Kmfv—Upper member of Menefee Formation
Kmv—Mesaverde Formation

Figure 8. Coal fields and coal areas in New Mexico part of San Juan Basin (from Shoemaker and Whyte, 1977, p. iv).

Pictured Cliffs Sandstone

This sandstone unit represents the final withdrawal of the Cretaceous epeiric seaway from the San Juan Basin area. Similar to the Point Lookout Sandstone below, the Pictured Cliffs is a coastal-barrier sandstone rising to the northeast in a series of steps before pinching out (Fassett, 1977, p. 194-5). The maximum thickness of the formation is 400 feet.

The contact between the Pictured Cliffs and overlying Kirtland Formation is recognized in the field by Fassett and Hinds (1971, p. 8) by the occurrence of Ophiomorpha major, a crustacean burrow. Thin limestones within the Pictured Cliffs have yielded both shark and other fish fossils.

In the northwest part of the basin where heavy mining is currently underway, the Pictured Cliffs lies below the coal-bearing Fruitland, and will thus not be removed by the stripping operations. The fossils of the Pictured Cliffs therefore will only be affected by indirect impact.

Fruitland Formation

The Fruitland Formation is the focus of this study. The bulk of coal reserves of the San Juan Basin are in this formation (Fig. 8). An abundant fossil fauna is present in the Fruitland Formation which includes many vertebrate remains, petrified wood and scattered, though significant, invertebrate fossils.

The Fruitland is a thick (0-500 feet) nonmarine deposit recording the advance of terrestrial sedimentation behind the retreating epeiric seaway in Late Cretaceous time. It is composed of carbonaceous shale, siltstone, sandstone and in most places thick coal beds (Fassett and Hinds, 1971, p. 3). Other than the coal in the Fruitland, its similarity with the Kirtland makes separation of the two units difficult.

Kirtland Shale

A unit of interbedded shale, siltstone and sandstone representing coastal or alluvial plain sedimentation, the Kirtland Shale attains a thickness of 1500 feet in the northwest part of the basin, and pinches out eastward. Molenaar (1977, p. 165), notes a change in the sediment source area for the Kirtland and Paleocene Animas Formation from the southwest to the north, northwest or west for younger units.

Tertiary Rocks

Ojo Alamo Sandstone

Paleocene strata overlie the Kirtland, the Ojo Alamo in the northwest part of the basin and the Animas (McDermott Member) in the north. The base of the Ojo Alamo is thought to be coincident with the Tertiary-Cretaceous boundary (Fassett and Hinds, 1971, p. 33).

The Ojo Alamo is a resistant, reasonably uniform fluvial sandstone with lenses of shale (Baltz, 1967, p. 32). It varies between zero and 250 feet in thickness, and forms a prominent stratigraphic marker in the northwest part of the basin.

Animas Formation

A probable partial correlative with the Ojo Alamo Sandstone, the Paleocene Animas Formation, is restricted to the northerly part of the San Juan Basin. Fassett and Hinds (1971, p. 33), characterize the Animas by its abundance of volcanic debris. This conglomeratic unit contains boulders and pebbles of andesite in a tuffaceous matrix. This unit is interbedded with shales and sandstones. Reeside (1924, p. 2) measured a section of Animas in southern Colorado which attained a thickness of 2670 feet. Laterally it interfingers into the Nacimiento Formation.

Nacimiento Formation

The Nacimiento Formation, which conformably overlies the Ojo Alamo Sandstone, is Early to Middle Paleocene in age based upon its rather abundant mammalian fauna. Pollen from a coal bed 130 feet above the base was dated Early Paleocene (Fassett and Hinds, 1971, p. 34). Lithogically, the Nacimiento is composed mainly of shale with interbedded sandstone. Molenaar (1977, p. xii) listed the thickness for the Nacimiento as 500 to 1300 feet.

Fossils of the Nacimiento are best known from the abundant mammal remains. They represent a classic fauna of Paleocene age in North America. Petrified wood, fossil leaves and fresh water invertebrates are less common.

San Jose Formation

The Eocene San Jose Formation is a sequence of sandstone and shale which in part is lacustrine. The thickness of the unit is 2500 feet (Molenaar, 1977, p. xii). This formation occurs in the north, northwest and southeast part of the basin (Baltz, 1967, p. 42), and rests everywhere in an unconformable relationship on the Nacimiento Formation (Baltz, 1967, p. 44).

Baltz (1967, p. 57) and Fassett and Hinds (1971, p. 34) described the presence of large numbers of biotite-hornblende lamprophyre dikes and sills cutting the San Jose Formation. These igneous bodies, ranging from one to 30 feet in thickness are associated with contemporaneous faults in the area.

Quaternary Deposits

Terrace gravel and colluvium of Quaternary age occur locally in the basin. Stream channel alluvium consisting of sand, silt, clay and gravel are present in all drainage channels throughout the San Juan Basin.

Structure

The San Juan Basin is a large Laramide structural basin on the eastern margin of the Colorado Plateau. The basin is asymmetric (Fig. 5), the northern flank being considerably more steep (60°) than the southern. Within the basin rocks are essentially horizontal with local dips rarely exceeding 2 degrees. Typical of Colorado Plateau basins, the San Juan is filled with a thick Cretaceous sequence capped locally with younger strata. Faulting within the basin is generally of minor proportions. Normal as well as some low angle thrust faults (Baltz, 1967, p. 62) are recorded. Minor normal faults, with displacement of less than 50 feet, were observed in several of the strip mines visited by the authors.

Fassett and Hinds (1971, p. 34) suggested an Early Eocene age for the initial development of the basin, or after the deposition of the Ojo Alamo, prior to the deposition of the San Jose. According to Woodward and Callender (1977, p. 212) the Nacimiento uplift was active after the Miocene.

Geologic History

The following is a sequence of major geologic events during Cretaceous and Cenozoic time, in order of ascending age, summarized from Fassett and Hinds (1971, p. 37-39).

1. Final retreat of marine conditions as the Pictured Cliffs Seaway withdrew to the northeast.
2. Non-marine, though near shore, conditions prevail following the retreat of the Pictured Cliffs Seaway, depositing Fruitland and Kirtland sediments. Swamp environments in this sequence were the basis of coal deposits in the San Juan Basin.

3. Volcanic rocks are formed in several parts of the basin from vents whose geographic position is unknown, though were likely at several sites around the rim of the basin.
4. Uplift of the southeast part of the present basin resulting in the erosion of an unknown thickness of Fruitland and Kirtland Formations.
5. Deposition of the Ojo Alamo as channel sands on the newly uplifted and eroded surface which was followed by deposition of the Nacimiento Formation represents the onset of the San Juan Basin structure.
6. Uplift of Hogback monocline in the northern and northeastern part of the basin. Erosion of the Fruitland, Kirtland, Ojo Alamo and possibly the Nacimeniento accompanied this uplift.
7. Volcanism along the northern margin of the basin and renewed uplift of the Hogback monocline with accompanied erosion of pre-San Juan rocks.
8. Deposition of the San Juan Formation in the Eocene followed in the Miocene by intrusive activity as dikes and sills, were emplaced in the northeastern part of the basin.
9. Deposition of local sequences of Quaternary sediment.

PALEONTOLOGY

History of Research

The earliest discovery and reporting of fossils in or near the San Juan Basin of New Mexico appears to be associated with the United States Government's geographical examination of New Mexico in the middle 1840s (see Abert, 1848 and Bailey, 1848). Cretaceous molluscs were reported in sandstones along the Rio Puerco a few miles west of Del Norte. Also in 1848, Wislizenus recognized petrified wood just outside the Basin near Cerrillos. He, too, found fossil invertebrates of Cretaceous age. These were associated with coal beds a few miles north of San Ygnacio. Bailey (1848) stated that these fossils proved the Cretaceous age of the coal beds in that region.

Substantial collecting of fossils and definitive reports on them began in the 1870s. In the field seasons of 1871 through 1874, U.S. geological and geographical surveys investigated the Territories west of the 100th Meridian which included study of the San Juan Basin in New Mexico. Cretaceous invertebrates, mostly molluscs, were collected and first identified and described by White in a preliminary report. In 1882 E. D. Cope was appointed paleontologist to the Hayden surveys, a position he held until 1879. The year prior to this appointment Cope made his first visit to the western Territories. However, he evidently did not get into New Mexico at this time. In 1874 Cope temporarily left the Hayden party which was working in an area he had seen on his earlier trip to join the Wheeler survey which was doing work in New Mexico. Upon joining this survey, Cope learned that one of its members, F. Klett, had found fossil vertebrates, evidently mammalian, the previous year. With this

lead, Cope began his first fossil vertebrate collecting in New Mexico. Following leads from local people, Cope discovered extensive Early Eocene vertebrates, mostly mammals, in the San Juan Basin. His first collecting here was presumably in Yegua Canyon in what is now considered the San Jose Formation. Cope considered this to be his most important find to date. During this same field season he moved to an area near Cuba, New Mexico where he named the deposits there the "Puerco marls." Cope did not find fossils in these beds at this time. They were later found by David Baldwin who worked for Cope from 1880 to 1888. Baldwin was a free-lance collector who earlier (1876 to 1880) collected for Cope's rival, O. C. Marsh. However, Marsh became dissatisfied with Baldwin and dispensed with his work. Apparently Marsh did not seriously study the New Mexico fossils collected by Baldwin as indicated by his not publishing any significant articles about them. He did make a passing reference to Coryphodon being present in New Mexico, though, based on material in the Yale Museum. Cope's publications on the Eocene and Paleocene vertebrates of the San Juan Basin were numerous and extended from the early 1870s to the late 1880s. Many of these articles concerned Paleocene vertebrates which Baldwin had found in Cope's "Puerco marls" (now recognized as the Nacimiento Formation). Cope was also the first person to publish on dinosaurs from the San Juan Basin (1885).

Invertebrate fossils from the San Juan Basin have not received the same attention as the fossil vertebrates, but several articles relating to them were written since C. A. White's early work. T. W. Stanton published on both marine and nonmarine invertebrates from the Cretaceous formations of the area (1893, 1912 [in Lee] and 1916). However, most published work on invertebrates has been a part of stratigraphic studies (e.g., Anderson, 1959; Lamb, 1964, 1968, 1969; Mannhard, 1976a, 1976b).

Plant fossils from the basin were evidently not seriously studied until the early 1900s. They were mentioned in an article by Shaler in 1907 relating to a preliminary survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico but these plants were purportedly few and fragmentary. An early listing of a fossil flora from the Basin apparently was made by Knowlton in Lee (1912). The earliest reasonably extensive coverage of fossil plants from this region was made by Knowlton (1916) when he discussed the flora of the Fruitland and Kirtland Formations. Study of fossil plants from the San Juan Basin since the early 1900s has been a little more extensive than that of invertebrates. Wieland intermittently worked on fossil plants from this region in the 1920s, 1930s and 1940s. Following him some work was done by Delevoryas (1959), Anderson (1959), and Brown (1962). These workers primarily studied plants from Cretaceous and Paleocene formations.

While studies of the invertebrate and plant fossils from the San Juan Basin have been few, work on fossil vertebrates has been extensive and has involved a multitude of investigators from Cope's initial studies to the present day. Following Cope, the American Museum of Natural History had several notable paleontologists research the fossil vertebrates of the Basin from the middle 1890s to the 1950s. A brief summary of these investigators, as well as others from various institutions, is given in Lucas (1977).

Development of Paleontology with Respect to the Law

Significant search for and recovery of fossils in the United States began in the latter half of the 19th century. It was about this point in time that paleontology came to be recognized as a useful, eclectic science. Fossils were first recovered and studied in the eastern states where the institutions of higher learning were located. With westward expansion, notice was soon made of vast rock exposures typical of the western states. They, too, were found to contain fossils. Early fossil hunting in the western States had its scientific beginnings in the United States' Government surveys of the territories. Separate geological surveys under the direction of F. V. Hayden, C. King and J. W. Powell uncovered many fossils, plant, invertebrate and vertebrate, which were sent to the early paleontologists in this country. Realizing the rich storehouse of fossils provided by the western territories, these scientists began requesting that specific information and, where possible, types of fossils be collected. Evaluating the new found data, the early paleontologists began sending their own personnel into the field (accompanying them at times) in order to better understand the new concepts that were developing concerning prehistoric life in America. This work stimulated paleontological research in other countries as well, especially those in Europe, and also directed the public's attention to paleontology. At this stage the science grew rapidly with many new students entering the field. The vast majority of this western land belonged to the Federal government and apparently no laws then existed to prevent those collecting fossils from taking what or how much they wanted. Fortunately, most of this material was scientifically cared for and can still be seen and studied at several institutions. However, with the increasing attention that fossils received, private individuals began collecting fossils also. While some of these individuals worked with paleontologists, many did not; and valuable

fossil materials became lost to science. This problem was even greater in the field of archaeology. In 1906, the American Antiquities Act was passed which made it unlawful for anyone to "appropriate, excavate, injure, or destroy any historic or prehistoric ruin or monument, or any object of antiquity, situated on lands owned or controlled by the Government of the United States, without the permission of the Secretary of the Department of the Government having jurisdiction over lands on which said antiquities are situated . . . ." This act also gave the president of the United States power to declare national historic landmarks, historic and prehistoric structures as monuments. The Antiquities Act was meant more to protect archaeological materials than paleontological ones, however. Although the Federal Government later interpreted "any object of antiquity" to include fossils, in reality fossil collecting by professional and nonprofessional alike was done on Federal lands almost entirely without securing permission. This remained the state of affairs for many years. As the country's population began increasing dramatically, and as more people had leisure time, the hobby of "rock hounding" (which includes fossil collecting) grew very rapidly. In addition, more people spent leisure time in fossil producing areas that previously were but infrequently visited. Although some nonprofessional fossil collectors informed professional paleontologists of their finds, many did not. As a result of this and of actual vandalism of fossils, as well as widespread construction, all growing at an alarming rate, paleontologists became ever more concerned about the significant loss of fossils. Both as individuals and as members of scientific societies, a number of paleontologists began petitioning State and Federal governments for fossil protection. The Federal government maintained that this could be done through the Antiquities Act. Court cases testing this act, however, showed that it was not sufficiently specific to allow

for adequate protection of fossils. In 1969, the National Environmental Policy Act was enacted which was meant to protect our country's environment and better control resources. Although later interpreted to include fossils, the act was again not specific enough for their protection and study. The same was true for the Archaeological and Historical Preservation Act of 1974. For a brief review of developments concerning paleontology and the Federal government, see C. M. McKinney's Paleontology and the Law in 11593 of the Office of Archaeology and Historic Preservation, vol. 2, No. 2, p. 1-2, 1977-78.

Although further clarification is yet needed, the federal government has proceeded under existing laws and their interpretations of them to protect fossils on government owned lands. In trying to properly manage its lands and protect valuable paleontological data contained in them, the government has required the following: 1, persons wishing to collect fossils must obtain written permission from them and 2, all development of lands for construction, mining, etc., must conduct preliminary paleontological as well as other surveys to determine direct and indirect impacts and their mitigation.

Paleontological Significance of the San Juan Basin

The government is aware of the need to allow development of the vast coal reserves in the San Juan Basin of New Mexico. It is also aware of its obligation to protect the paleontological resources that occur there. The present study attempts to show how the much needed coal can be recovered with minimal loss of paleontological resources. It is clear that the major loss of fossils will be the result of strip mining which is occurring now and will occur more extensively in the future. With the expected influx of people in the area, it can be safely predicted that illegal fossil collecting

and vandalism of fossils will significantly increase. All reasonable steps possible should be taken to insure that paleontological loss be kept minimal. The San Juan Basin of New Mexico contains one of this country's more significant paleontological deposits. The information that can yet be gleaned from fossils there is highly important. It contains a record of terrestrial life missing in all but a few areas on earth of the transition between two geologic eras, the Mesozoic and Cenozoic. Within the San Juan Basin is recorded the time representing the extinction of the dinosaurs. Material and data scientifically recovered there may furnish at least part of the reason why these giant reptiles became extinct. The earliest chapter in the Age of Mammals is also contained in the Basin's rocks. Many questions pertaining to the rise and dominance of these animals can be answered by careful study of fossils from this area. Although fresh-water invertebrates are abundant in the Basin's Cretaceous rocks, little scientific research has been done on them. Numerous plant fossils are also available and need more study. Since both plant and animal fossils are abundant, studies involving the interrelationships between them can be made. This is an important area of research which has hardly been touched. In-place fossil forests also offer unique research possibilities. Many paleontologists have noted the importance of San Juan Basin fossils. The scientific value of these fossils is exceptionally high and should not be underestimated.

Fossil Occurrences

Surface Mines

Fossil plants, vertebrates, and invertebrates were encountered in the various strip mines in which we visited and worked. Plant remains are the most common (Table I), although in some horizons the invertebrates form thin coquina beds. These were observed in the highwall of the San Juan Mine about 50 feet above its base with the white shells contrasting with the much darker rocks. This fossil bed was three to four inches in thickness and extended horizontally for about 150 feet. Specimens consisting largely of Unio sp. were recovered from rock materials that had fallen from the highwall. For safety reasons, the specimens had to be removed quickly from near the base of the unstable highwall.

Only a portion of the Menefee, Crevasse Canyon, and Fruitland floras were seen in the strip mines. The conifer Araucaria was the most common plant fossil throughout the various pits visited. Specimens of this genus were seen in the Amcoal #1, Carbon, McKinley, and San Juan Mines. This genus was noted in spoil piles and highwalls several feet above the coal seams in the mines. Sequoia foliage was found in the McKinley Mine.

Palm leaves assignable to both the fan palm Sabalites and feather palms Phoenocites were fairly abundant. They occur in the spoil piles and above the coal in their highwall. The fern Osmunda was collected from the highwall above the coal in the Yucca pit of the San Juan Mine.

Dicotyledoneous leaves are numerous in the spoil piles of the different mines. Although dicots are common, individual genera, with the exception of Ficus and Salix, apparently are not that abundant. Rhamnites of the buckhorn family (Rhamnaceae) was occasionally encountered.

Petrified logs which are relatively abundant in other parts of the Fruitland Formation were not seen in the pits. Miners reported they were very rare. One stump from the Crevasse Canyon Sandstone was noted in the spoil piles of the Carbon Mine. The stump, preserved originally in growth position, appeared to be a taxodiaceous form, possibly Sequoia.

Underground Mines

Fossils were only encountered occasionally in underground mines. They are mostly plant and vertebrate fossils with invertebrates being relatively rare.

The preservation of the fossil plant materials consists of three types. These are: 1) compressions of both leaves and stems, 2) upright stumps showing extensive root systems which are generally coalified and 3) petrified woods of various shapes and sizes.

The leaf compressions are represented by palm fronds of Sabalites (fan palms) and Geonomites (feather palms), twigs of Araucaria and various genera of dicot leaves. Male and female flower stalks of palms were observed in the roof of one mine. These are very rare in the fossil record.

The stumps in the mine roofs are of dicotyledoneous, monocotyledoneous, and coniferous types. The root systems of these stumps were oriented in a NE-SW direction. An explanation for this phenomena is that these root systems were compensating for the prevailing wind direction. Horizontal logs in the mine roofs seemed to have been oriented by highwater floating of the logs. Some, however, are randomly oriented, indicating random current directions in the swamps. The close proximity of dinosaur footprints to these logs suggests that many of them may have been knocked down by these ponderous reptiles as they moved about.

Invertebrates were observed within the logs. These were fresh water clams that burrowed in the logs in a manner similar to the modern, boring bivalve Teredo or "shipworm."

The coniferous stumps possibly represent a taxodiaceous form related most likely to Sequoia cuneata. The palm bases are small and probably are related to Geonomites imperalis, a palm leaf of Cretaceous age. This palm species may have formed a common, shrubby, understory plant in the coal-forming swamps. This plant possibly grew along the margins of the swamps, shedding leaves into the peat that was forming. These palms, as indicated by their fossil remains, were locally abundant. Many of the individual palm stumps are as close as 1 meter apart. In areas outside of the mines, these palm thickets have been observed in overhanging ledges. The leaves of these palms (Geonomites imperalis) were apparently shed and accumulated around their trunks forming mats of numerous leaves. These palms may have been small "stemless" or short stemmed types similar to the living taxa Geonoma.

The dicot leaves are represented by species of Cornus, Dryophyllum, Ficus, Myrtophyllum, and Rhamnites. Parker (1976) considered the fossil dicot Rhamnites eminens and the fossil conifer Sequoia cuneata as co-dominant trees in the Cretaceous coal-forming swamps. This is similar to the modern forests in existing swamps on the Mississippi River floodplain where bald cypress (Taxodium distichum) a conifer and water tupelo (Nyssa aquatica), a dicotyledon, are co-dominant trees in their plant community. The foliage of the modern co-dominants is similar morphologically to those of their fossil counterparts (Parker, 1976).

Fossil evidences of vertebrates in the underground mines are dinosaur footprints and an occasional bone. There was a report by a miner of an entire dinosaur outlined in the roof of one mine.

Dinosaur footprints are rather common in the roofs of some sections of mines in Cretaceous strata, particularly those of Mesa Verde age or equivalent. These footprints are casts of where the dinosaurs had been walking on the surface of the "spongy" peat bog. These later filled with sediment forming the casts. They are exposed when the coal, formed from the peat, is mined away.

Based upon the configuration of the footprints, there appears to have been at least five types of dinosaurs involved. Much can be observed about dinosaur habits from the patterns of these tracks. Footprints show where dinosaurs stepped on or over logs as they moved about the swamp. Some footprints are situated on the root system of a stump. This suggests either the animal was resting, or more likely it was feeding on the upper reaches of the tree. This supports Ostrom's (1964) concept that these herbivores ate the coarser vegetation of the abundant woody conifers and angiosperms. The footprints show these animals were moving leisurely on the peat, indicating that they did not seem to be threatened. One track form, however, was observed to be following another, suggesting something may have happened to one or the other beyond the exposure of the mine roof. The thickness and size of these casts may give us a clue as to the weight and size of the animals making them.

Table I

FLORA OF THE FRUITLAND/KIRTLAND FORMATIONS

A. Knowlton (1916)
B. Lee (1917) near Dulce, N.M.
C. O'Sullivan et al. (1972)
D. Kues et al. (1977)
E. This report.

Filicophyta
- Osmundaceae
  - Osmunda boilicki E
  - Cladophlebis sp. D
- Schizaeaceae
  - Anemia hesperia A,B
  - Anemia sp.
- Cyathaceae
  - Cyathea pinnata D
- Polypodiaceae
  - Asplenium neomexicana A
  - Asplenium Coloradense E
  - Onoclea neomexicana A

Coniferophyta
- Araucariaceae
  - Araucaria longifolia A, B, C, D, E
- Cupressaceae
  - Brachyphyllum macrocarpum B
- Taxodiaceae
  - Sequoia reichenbachii A, B, C
  - Sequoia obovata A
  - Sequoia cuneata (= Metasequoia cuneata) C
  - Cupressinoxylon sp. E
- Coniferales incertae sedis
  - Podozamites sp. D

Anthophyta (Angiosperms)
- Dicotylendonae
  - Salicaceae
    - Salix baueri A
    - Salix sp. A
  - Juglandaceae
    - Carya antiquorum E (= Juglans nigella)
  - Fagaceae
    - Quercus baueri A
  - Moraceae
    - Ficus squarrosa? A
    - F. rhamnoides A
    - F. planicostata A, B, C, E
    - F. praetrinervis B
    - F. starkvillensis? B
    - F. curta A
    - F. wardii B
    - F. baueri A,E
    - F. sp. A, D

Nymphaeaceae
Nelumbo sp. A
Cercidiphyllaceae
Cercidiphyllum sp. E
Menispermaceae
Menispermites sp. A
(= *Ficus* sp.)
Magnoliaceae
Magnolia cordifolia E
(= *Ficus uncata* by Brown)
Lauraceae
Laurus baueri A
L. coloradensis A
Cinnamomum sezannense A
(= *Ficus eucalyptifolia*)
Saxifragaceae
Ribes neomexicana A
Leguminosae
Leguminosites? neomexicana A
L. sp. E
Rhamnaceae
Rhamnus goldianus E
R. cleburni C
(= *Dillenites cleburni* (Lesq., Dorf)
Zizyphus sp. B
Bignoniaceae
Dombeyopsis obtusa C
Myrtaceae
Myrtophyllum torreyi A, E
M. neomexicanum A
Cornaceae
Cornus coloradense E
Incertae sedis
Phyllites neomexicanus A
P. petiolatus A
Pterospermites undulatus A
P. sp. A
Carpites baueri A
Carpites cf. *lancensis* E
petrified angiosperm

Monocotyledonae
Sparganiaceae
Sparganium sp. D
Cyperaceae
Cyperacites sp. D
Palmae
Sabalites montana A, B, D
Phoenocites? sp. D
Palmoxylon sp. D, E
Palmoxylon sp. E
Palmoxylon sp. E
Rhizopalmoxylon sp. D
Araceae
Pistia corrugata A
Pontederiaceae
Heteranthera cretacea A

MINING

Mining History in the San Juan Basin

Coal, as a fossil fuel, is one of the basic natural resources of New Mexico. Its production, distribution, and utilization as an energy source influences directly and indirectly almost every phase of community and state well-being. Of New Mexico's 121,666 square miles of surface, approximately 14,650 square miles (12 percent) is underlain by coal (Frost, 1978). According to Frost (1978), the total coal deposits in New Mexico equal an estimated 180.5 billion short tons of this resource. Of this amount, 6.4 billion short tons (3.5 percent) are considered strippable.

The three major coal deposits in New Mexico are: 1) the Fruitland Formation and the Mesa Verde Group in the San Juan Basin, 2) the Mesa Verde Group of central New Mexico and 3) the Vermejo and Raton formations of the Raton Basin.

The coal in these formations was formed from an accumulation of vegetative materials in a series of ancient swamps. These coal swamps occurred in New Mexico approximately 50-100 million years ago during late Cretaceous and early Tertiary times. The coal deposits in the Fruitland Formation, as an example, suggest a belt of swamps from 6 to 20 miles wide with individual swamps ranging from small bogs to inundated areas of more than 100 square miles (Fassett and Hinds, 1971). This belt of long, rather narrow swamps was dissected by winding distributaries of sluggish streams, while broad, low flood plains encroached upon the swamps from their landward sides.

The existance of this coal in the San Juan Basin has been known to man for a long time (e.g., Bailey, 1848). It is thought that Indians may have burned coal in their kivas along the San Juan River some 1000 years ago. However, until recently, there was little interest in developing these vast coal reserves. This was due largely to the lack of a major market for this resource. Small mines for local consumption have existed off and on throughout the basin for years,

such as the mining activity near Cuba and La Ventana. This was an active coal mining area during the 1920's and 30's with minor activity until the 1960's.

However, a resurgence of interest in the San Juan coal began in the early 1960's with the opening of two large strip mines. One of these was the McKinley mine near Gallup and the other the Navajo Mine near Farmington. The McKinley Mine was the first coal property developed for the utility market of the Southwest. Coal at this mine is produced for Arizona's Public Services Cholla Power Plant at Joseph City, Arizona. In 1963, the Navajo Mine commenced deliveries of coal to Arizona's Public Services' Four Corner Power Plant. Production from these mines has increased steadily from approximately 3 million tons in the early 1960's to over 11.5 million tons in 1977 (Frost, 1978). Most of this tonnage is from three large strip-mines in the Basin. The mine-mouth power plants supplied from the Navajo and San Juan Mines near Farmington constitute the largest single concentration of electrical generating facilities west of the Mississippi River (Frost, 1978).

Current production is from six mines with four more planned for the early 1980's. The other three mines are the Amcoal #1, a small surface mine near Gallup that sends coal to cement plants in Arizona and California, the Carbon Mine near Gallup that supplies Arizona Public Services, and the York Canyon Mines near Raton that ships high quality coking coal to Kaiser's steel mills in Fontana, Calfiornia.

Mining Procedures

Current, and future, methods of mining are very real constraints to any proposed fossil mitigation plan. Coal mining in the San Juan Basin is of the area surface type on both a large and small scale. In this study, the following mines were investigated with the cooperation and help of company officers: San Juan Mine, Farmington, New Mexico; Navajo Mine, Fruitland, New Mexico; McKinley Mine, Gallup, New Mexico; Amcoal Mine, Gallup, New Mexico; Carbon Coal Co., Gallup, New Mexico; U.S. Steel Mine, East Carbon City, Utah; and Kaiser Steel York Canyon Mine, Raton, New Mexico. U.S. Steel and Kaiser Steel mines are underground operations while the others are strip mines of various sizes. All but U.S. Steel's mine in Utah and the York Canyon Mine are located within or on the margin of the San Juan Basin, New Mexico.

Underground Mining

Current underground, or deep, mining methods can be classified into three major types: conventional, continuous, and long wall. Local geology, available work force and expertise and economic conditions are among the determining factors in selection of any particular type of mining plan. The two deep operating mines visited in this study use all three methods, though operations are of the continuous type.

Conventional mining methods utilize cutting, drilling, blasting, loading, and hauling steps in their operations. Mining of this sort is limited to small operations and in special situations in larger mines.

Continuous mining methods use a continuous mining machine which rips the coal from the face and loads it into haulage vehicles. The operation is not truly continuous because empty shuttle cars must be regularly positioned to replace the full cars. The mining machine is partly inactive during this switching. Coal mined by continuous methods requires no cutting, drilling, or blasting. Typically, room and pillar methods of coal extraction are used in the continuous coal mining plan. A checkerboard pattern is developed in the mine with pillars of coal remaining as the rooms are fully excavated. This plan removes approximately 50 percent of the coal to this stage. Final operations require the removal of the pillars wherever possible increasing the yield of the coal seam to nearly 100 percent. The pillars are removed from the deepest part of the mine first and the coal is removed back towards the entries. The unsupported roof caves closing the strata which once underlaid and overlaid the coal bed. Safety supports timbers, roof bolts, etc. in the rooms and tunnels are abandoned.

Long wall mining was developed in Europe (mainly Germany). It is the newest method of coal mining and is becoming more popular as a highly productive method of coal extraction. This operation uses a longwall mining machine which cuts or shears coal directly from a face, approximately 500 feet long, hence the name. The coal is spilled directly on a conveyor belt for hauling. The machine, which has its own built-in hydraulic roof supports, retreats from the distal margin of a panel so that the longwall retreats or advances. Caving of the roof follows immediately behind. In this method, relatively few timbers or roof bolts are used. Safety for the mine personnel is accomplished very well by the movable hydraulic jacks in the roof support structure.

Most mines employ a combination of these procedures: Conventional methods for special underground structures and continuous mines to lay out and prepare

the panels for a longwall operation. The York Canyon Mine in Raton, New Mexico, is an example of a multiple operation in which continuous mining room and pillar and longwall mining are both used.

Methods of deep mining in the future may utilize variations of the longwall method by supplementing, or replacing, the shearing mode of the longwall mining machine with horizontal augers which could remove most of the coal between development entries by closely spaced large augers. Roof support may be accomplished by temporary air bags inserted into the auger holes. Caving would follow the retreat of the operation as the air bags are removed (Chironis, 1977, p. 62).

Safety procedures in operation throughout the underground coal mining industry include the application of rock dust, a mixture of pulverized rock and lime as a thick dry layer on the mine floor, and a thin layer applied in liquid form to the walls and roof. This crating reduces the hazard of a coal dust explosion. It also thoroughly covers any fossil material exposed in the roof or walls of the mine. Rock dusting closely follows the roof bolting procedures which leaves very little time between exposure of a fossil in the mine and its burial by the application of rock dust.

Coal is transported from the working face in shuttle cars or directly on conveyor belts to a processing plant near the mine mouth where crushing and washing are usually accomplished. Beyond the processing plant, most coal is moved to the consumer via rail or truck. Some operations are unitized, moving coal from the processing plant at the mine-mouth directly to a power plant for consumption as steam coal used in coal-fired electrical generating plants. Both the San Juan and Navajo Mines are of the latter type.

Area Surface Mining

Most coal produced at the present time in the San Juan Basin is being mined by large earth-moving equipment in surface or strip mines. For coal which is relatively close to the surface in an area of low relief, area surface mining is by far the most economical method of extraction. Present methods of reclamation make surface mining a highly beneficial means of coal mining.

Surface mining consists of a sequence of operations as the total mining operation moves across the countryside. Overburden is first leveled, drilled by vertical drilling machines, blasted to loosen the material, then removed to one side by draglines whose capacity can exceed 180 cubic yards, or smaller shovels in more modest operations (Fig. 9; Pls. 1, 2, 3, 11). The coal now exposed in the cut is drilled and shot. It is then removed generally by front end loaders filling large capacity (up to 120 ton) trucks. Removal of the coal may consist of several successive operations for multiple seam operations such as the McKinley Mine near Gallup, New Mexico.

Following the coal removal, the cut is filled by the overburden from the new adjacent cut. The spoil piles resulting from these successive cuts and fills are then graded to an acceptable surface, covered with top soil, and reseeded for reclamation as grazing land, etc.

In the process of strip mining, the juncture between a cut and the adjacent unmined area consists of a single vertical wall, or highwall, or in some cases, a series of steps as multiple seams are mined. Potential fossil-bearing localities could be found in the course of preliminary study prior to any preparation, in the initial leveling process prior to drilling and blasting, during the process of overburden removal, or as exposures in the highwall.

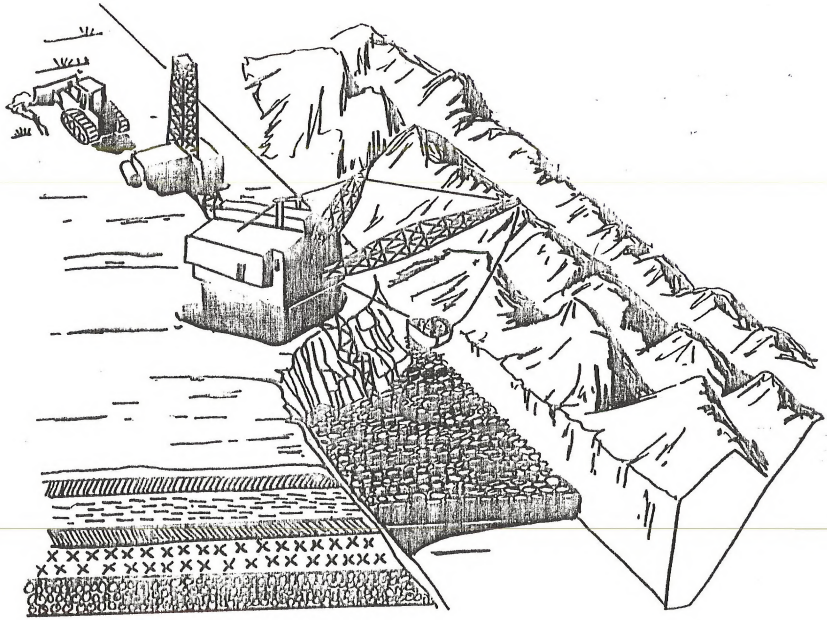


Figure 9. Diagram showing typical area surface mining operation. Coal and overburden are shown at left, exposed coal seam in middle and spoil piles on right. Equipment illustrates site preparation, overburden drilling and dragline for overburden removal. In practice these operations may be separated by several weeks.

In smaller operations such as the Amcoal Mine near Gallup, New Mexico, the same basic mining plan is being accomplished at a much reduced scale with the use of power shovels for overburden removal, bulldozer and front end loaders for coal removal and loading, and hauling with highway-size trucks.

As in underground operations, once the mined coal is transported to a processing plant for crushing and washing, thence to either unit trains for haulage or by truck or conveyor belt directly to a coal-fired electric generating plant adjacent to the mining operation.

Any mitigation procedure will be, to some extent, controlled by available equipment at the mine and mine safety regulations. At the present time types of equipment in use in area surface mining operations within the San Juan Basin are similar. For planning, use the following table (Table II) that has been prepared indicating the types and sizes of equipment in use at the various mines within the basin.

Table II.

CHART SHOWING AVAILABLE EARTH-MOVING EQUIPMENT IN USE

FOR SURFACE MINING IN THE SAN JUAN BASIN

MINE	DRAG LINES	FRONT-END LOADERS	SHOVELS	BULLDOZER	TRUCKS
Navajo	63 yd^3	23 yd^3	11 yd^3	?	120 ton
Utah Internatl.		18 yd^3	16 yd^3		
San Juan Western Coal	63 yd^3	20 yd^3?	11 yd^3 16 yd^3	?	120 ton
McKinley P & M	55 yd^3	20 yd^3	16 yd^3 11 yd^3	?	120 ton 100 ton
Amcoal	7 1/2 yd^3	?	---	D-9	?
Carbon Coal					

Testing

In visiting various strip mines in the San Juan Basin, it became apparent that fossil collecting in these mines has to be limited to the spoil piles or by utilzing the draglines and, where possible, front end loaders in collecting from the highwalls. Because of the amount of rock that has to be moved to obtain fossils and the safety factors which must be observed without disrupting the mine workings, these shovels have to be used. Concerning safety (which should be of prime importance) rock debris can fall from the highwall at any time either as single boulders or, as was observed, entire sheets of rock sliding into the pit.

In order to determine the effectiveness of the draglines in collecting, it was necessary to see what happens to fossil materials after being dumped from the bucket either upon the spoil pile or the highwall pad. Because no fossil materials were immediately available in the highwall to test this effect, boulders in or on the highwall were painted various colors (Pl. 8a, 8b). These simulated fossils constituted part of the overburden above the coal. Since fossils occur in different positions relative to the working face of the highwall, various colors were used to denote these positions. Dependent upon their position in the working face, the bucket affects the fossil-containing rock differently. Thus, it was anticipated that by using different colors the progress of these rocks could be followed through the overburden removal process.

The boulders on the face of the working wall were painted flame on pink. Those on the east face were colored gold and those on top became red, green, salmon, blue, and orange (Table III). As these colored boulders were scooped up and deposited, the action of the bucket of the dragline was observed and photographed (Pl. 9). Two buckets of material were placed upon the pad and subsequently analyzed to see how the colored materials representing the fossils, had fared (Pl. 10b).

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During the removal of the painted boulders, the bucket scooping through the overburden forced the simulated fossil materials to the top of the bucket. Consequently, upon dumping, these materials were the first to drop and were then covered with the remainder of the rock debris. Thus, a fossil-containing rock would have been deposited at the bottom of the pile in a difficult position for its collection. As the bucket moves up and away from the face, some rock debris is lost over the lip of the scoop. Some of the painted surfaces were lost in this way. Another possible problem occurs when the material in the bucket is dumped. The material is dropped while the bucket is 15 to 60 feet in the air. This further breaks up the rock. Although this would aid in finding fossil remains, any large fossils would likely be broken. A skilled operator could possibly lessen this impact.

The exposed surface area of the painted boulders was first computed for the piles before scooping and then immediately after dumping. The piles were, subsequently, spread out by bulldozing and the percentages of exposure of these colored surfaces again determined (Pl. 10). Of the original painted surfaces, approximately 32% of the salmon and 51% of the flame on pink appeared on the piles immediately after dumping. The other colors did not appear. After spreading the piles, 19.6% of the salmon and 34% of the flame on pink were observed in the first pile. In the second pile, 43.6% of the salmon was exposed and 4.4% of the flame on pink.

These buckets were taken from the top of the exposed highwall which accounts for the larger percentage of salmon. Although the percentage of the salmon is relatively high, it is still smaller than the area of the original painted surfaces. Thus, it appears that if a fossil was observed in the working wall, scooped up and then dumped on the pad mixed with the 63 cubic yards of rock debris from the bucket, the chance of finding it again would be rather small.

The painted boulders dropped from the bucket upon the spoil pile were never seen again. They were soon buried by subsequent buckets of rock debris.

The accurate operation of these large draglines is very important for successful collecting of fossils from the highwall. This is dependent upon the skill of the operator. Some with practice are able to scoop up rock materials from a relatively precise horizon. However, this "precise" area is still rather large and their ability to pinpoint a specific fossil is certainly limited. The field of vision of the bucket over the highwall from the dragline control panel is rather restricted. Much of the operation is by "feel." A capability at which the operators are highly skilled.

After a few fossils were observed above the coal in the highwall, a bucket of material from this level was dumped on the pad. With the exception of a few coalified plants, notably Araucaria and Phoenocites, these sediments were devoid of recognizable fossils. This was unexpected, but after further observations of the highwalls, there appears to be a relative paucity of fossil remains in the exposed rock above the coal.

Investigation of the spoil piles involved climbing over the various piles in the Yucca pit of the San Juan Mine to observe collectible fossils (Pl. 5a, 5b). Many plant and invertebrate remains were encountered. The only vertebrates found were part of a turtle plastron and some unidentifiable bone debris. The problem of collecting in the spoil piles is twofold. The first is in not knowing stratigraphically from whence the fossils came. Various rock units become intermixed and the determination of the precise horizon of their occurrence in the highwall is difficult. However, this problem could be possibly corrected with a concentrated study of the lithologies associated with the fossils and relating them to those in the highwall. The second part of the problem is that for safety reasons collecting can begin only on those piles that have existed

for a period of time (three weeks or longer) and, thus, have become stabilized. Unfortunately, the fossils by this time have begun weathering. Although some leaves were nearly complete, only a few were collected whole. They disintegrated while attempting to remove them from their rock matrix.

Looking for fossil vertebrates consisted of searching spoil piles in much the same manner as in searching other exposed rock areas. The bases of the piles were examined for bone fragments, then searching continued upwards toward the tops. Notice was taken of the rock types and the areas opposite the high wall that tended to produce fossils. More search time was then put in on those areas and those rock types which were deemed most productive. The slope of the spoil piles allowed for close-up inspection for small vertebrates without the usual searching on hands and knees. Continuing standard practices of recovering fossils, various strata, representing different lithologies, were screen washed (Pl. 7). Sediments were passed through both large and small mesh screens (details relating to these techniques are explained under collecting procedure).

Invertebrates collected from spoil piles were generally well preserved. Approximately 150 specimens, ranging from fragments to entire shells were collected from the spoil piles at the San Juan Mine. These invertebrates were almost exclusively the fresh water bivalves Unio, although a few gastropods were also collected.

The weathering process of the fossils was more advanced in the investigated spoil piles that were further from the pits. The reason for the fairly rapid weathering was probably due to the high clay content of the fossiliferous zones. The yield in terms of identifiable fossils from these piles was small. Although considerable effort was expended, many of the fossils uncovered (with the exception of invertebrates) were beyond salvaging.

Table III. Summary of the Experiment with the Painted Surfaces

Color and Location on Working Wall	Original Painted Area	Exposed Painted Surfaces After Dumping	Exposed Painted Surfaces After Spreading w/Dozer			
			1st Pile		2nd Pile	
			previously viewed before dozing	newly viewed after dozing	previously viewed after dozing	newly viewed after dozing
Yellow (east face)	10 ft^2	0	0	0	0	0
(boulder bottom)	136.5 ft^2	0	0	0	0	0
Salmon (top)	112 ft^2	35 3/4 ft^2	14 3/8 ft^2	6 5/8 ft^2	0	32 ft^2
Flame on Pink (south face)	114 ft^2	18 ft^2	12 1/8 ft^2	1/4 ft^2	0	5 ft^2
Inca Gold (east face)	75 ft^2	0	0	0	0	0
Central Pile (on top of working wall)						
Pink (west side)	30.5 ft^2	0	0	0	0	0
Bloodred (south end)	35 ft^2	0	0	0	0	0
Green (east side)	45.5 ft^2	0	0	0	0	0
Blue (top of pile)	68.5 ft^2	0	0	0	0	0
Purple (north end)	39.6 ft^2	0	0	0	0	0

SALVAGE

Plants

Fossil plants in the Fruitland Formation are relatively abundant. These plant remains consist of both leaf compressions and petrified wood. Much of the latter is well preserved and essentially unstudied. The opportunity for studying these petrified materials in the San Juan Basin is unique. To find a petrified stump forest above the coal is very unusual. An example of a study that should be done is to relate these stumps to those seen in the mine roofs. In the underground mines, stump specimens would have to be studied from a root view, whereas the stumps in the petrified forest can be studied from above. Each view would contribute information to an overall study. From a study of these woods, their taxonomy, growth habits, paleoenvironments, paleogeographic distribution and possible evolutionary trends could be determined. These petrified materials, wherever possible, should be salvaged.

The compressional materials in the Fruitland Formation are not only abundant but varied. These fossil plants have not been adequately studied. In the salvage testing, 65 specimens were removed. Because of the limitation of the area (1 cubic meter) in which the collection was made only a relatively small number were obtained. However, the number of specimens in this limited area indicates the abundance of fossil plants in some horizons of the Fruitland Formation. The time-cost ratio is 5.4 specimens/man hour. In salvaging where the landscape will eventually be mined, a bulldozer could scrape away the overburden and expose the fossil horizon. Many specimens could then be obtained relatively cheaply.

The specimens collected from the test plot are divided taxonomically into one fern, two conifer and ten dicot species. Pieces of petrified palm axes

were encountered at a different locality in the Fruitland Formation. This Palmoxylon species is one of three from this formation. The other two are from near Cuba, New Mexico. Cretaceous Palmoxylons are rare. Only four or five other species have been previously reported from North America. Thus, these specimens from the San Juan Basin become scientifically important. With a more comprehensive study all three may eventually be found in the central and northern portions of the San Juan Basin.

All these fossil remains should be salvaged where applicable. Much is yet to be learned from this unique area.

Time-Cost Study of Fossil Plant Material

Bisti Area: Fruitland Formation.

Occurrences: Various leaf compressions mostly of angiospermous types.

Lithology: Silty shale with interbedded sandstone beds. Fossil plants were collected from the finer silty shales.

Collections: Approximately 65 specimens of mostly usable materials. Identification of most angiospermous leaf materials require fairly complete leaves. One leaf contained the remains of one of the oldest known leaf mines.

Time/Cost: Approximately 5.4 specimens per man hour (65 specimens were collected by 3 men in 4 hours).

Bisti Area: Fruitland Formation.

Occurrence: Logs of petrified wood of various lengths. Leaf compressions were associated with them.

Lithology: Silty shale with sandstone layers.

Collections: One log of petrified wood.

Time/Cost:

Approximately 24 man hours were utilized in the collection of this material. Estimation of the hauling miles to a repository (Albuquerque) was 155 miles. Cost of specialized equipment is estimated at $400. This consisted of a flat bed truck with a hoist for lifting heavy materials.

Vertebrates

Collecting Procedures

Many areas in the San Juan Basin, which have previously yielded vertebrate fossils, were examined in an attempt to determine fossil densities, general types of fossils, state of preservation, nature of occurrence and the degree of difficulty in collecting them. These searches were made primarily in the Kirtland and Fruitland formations, but the Ojo Alamo and Nacimiento formations were also examined. Fossil site selection was determined in large measure by localities previously discovered in a recent fossil survey of the San Juan Basin (Kues et al., 1977). The major purpose in examining these localities was to determine the salvageability of fossils in view of large-scale coal mining anticipated in the Basin in the near future.

Field parties of from three to seven people would walk over areas which were likely to produce fossils. The standard technique of spreading people out and working up small washes and slopes was employed. When bone fragments were detected, searching became more critical in that area. If the specimens were small they would be collected by direct pick-up, if already freed from the matrix, or by working them out of the matrix using one or a combination of hand pick, rock hammer, awl and dental tools. Only hand-held equipment, none of it power driven, was used in collecting fossils. Specimens would then be wrapped in tissue, put in a vial if very small, or placed in a paper bag and sealed. Date, field number and location would then be written on the container. Field notes were taken where fossils were collected. These included topographic map location, date, geologic formation present, lithology of fossil-bearing unit and other significant geologic data, types of fossils found and their condition, state of preservation, etc. and any other information considered relevant.

Larger specimens such as dinosaur bones were collected in plaster jackets (Pl. 4a, 4c). The technique used here was to first remove as much matrix as necessary to determine the overall size and shape of the bone(s); a pick and shovel were used further out from the fossil, and small tools and brushes employed when near the bone surface. Gelva and/or thinned glyptal were used as hardeners to protect the bone surface and white glue was used to attach broken pieces. After allowing a sufficient time for drying, the bone surface was covered with a slurry of wet sand or mud for protection. A trench was next cut around the fossil to a depth slightly greater than the maximum extent of the fossil. The specimen was then undercut just enough to allow securing of the plaster jacket around it. Plaster mixed with sand and water to a viscous consistency was molded around the specimen. Additionally, burlap soaked in plaster was added and let dry until a tough, protective jacket was formed. When a stronger jacket was needed for a very heavy specimen, wooden stakes were adhered by wrapping burlap soaked in plaster around them. After the plaster jacket dried, the specimen was turned over. Excess matrix was removed and plaster jacketing completed to encase the entire fossil. Date and field number were carved in the jacket and notes pertaining to the specimen completed. The jacketed specimen would then be loaded into the truck on blocks and later brought to the lab for preparation.

Cretaceous, and to a limited extent Paleocene, strata were sampled at widely separated sites for small vertebrates. Since even close visual inspection is usually inadequate for this, screen washing techniques were used. Various lithologies from clay to gravel were sampled. Both weathered and fresh rock materials were collected by pick and shovel and put into standard sized gunny sacks; about 70 pounds per bag. Locality data were placed on cards with one card kept inside with the matrix and the other tied to the closed mouth of the bag. As with other types of collecting, field notes were

taken at each separate locality. The number of sacks per locality varied from 1 to 10. In some cases the rock unit was too well indurated to collect with any facility, but a sample was considered desirable nevertheless. A single bag was collected in these instances. No more than one cubic meter of rock material was taken from a specific site. The partially filled gunny sacks were then loaded onto a truck and taken to the nearest adequate water source for screening. Better results were obtained by soaking the bags for a 12 to 24 hour period before attempting to pass the matrix through the screens. In the actual screen washing operation, a managable amount of sediment was put into a wooden frame screen of larger mesh which was nestled into a similar framed screen, but with smaller mesh (size of wooden frame screens used was 45.5 cm long, 40.0 cm wide and 14 cm deep; large mesh was 5 mm squares, and small mesh 1 mm squares). The double screens (up to 10 were used) were agitated by hand to allow separation of the sediment until only materials larger than 5 mm remained in the upper screen. This screen was then closely checked for fossils. The finer mesh screen was subsequently shaken until materials with a diameter less than 1 mm passed through. Matrix remaining in the screen was emptied onto a large plastic sheet and allowed to dry. Later, easily discerned fossils were picked out, placed in vials and labeled. The remaining concentrate was labeled and bagged for further processing in the lab where it was put in small cardboard trays and searched by the use of a binocular microscope (zoom lens, 0.7X to 4.0X with a 15X eyepiece). Sediments with a high clay content did not readily break down in water. Thus these deposits were soaked in kerosene, on a sample basis, to see if better results could be obtained. After overnight soaking, the sediment was put on a plastic sheet and allowed to dry. It was next put back into a fine screen and soaked in water. Unfortunately this method was no more successful than the use of water alone. A 0.5 mm square screen was also

used on various sediments on a trial basis. The sediment samples used did not readily pass through this fine screen so it was not employed further.

Preparation of collected fossils was done in a paleontological laboratory. As indicated above, the final stages of the screening process were done in the lab. Specimens collected by surface pick-up or in plaster jackets were cleaned and prepared here using standard paleontological equipment and materials.

Collecting Results

One of the main purposes of the present study has been to determine the salvage feasibility of various types of fossil materials in areas of direct and indirect impact. Due to changed time constraints, salvage testing was not as extensive as originally anticipated. However, enough areas were examined to determine fossil salvage feasibility under the varying conditions which could exist.

Several strip mines were inspected for evidence of fossils. Amcoal, Carbon and P and M Coal companies near Gallup, New Mexico, all permitted access to their mine areas enabling us to gather needed data which included searching for fossils. Although plant fossils in these mines were fairly abundant, and in some instances well preserved, no vertebrate materials were seen. Western Coal Company near Farmington, New Mexico, was very cooperative in allowing us extensive access to all areas of its mining operation which were safe to investigate. Approximately one week was spent examining the various pits of the San Juan mine. Various lithologies of the Fruitland Formation were exposed here and each was closely checked for fossils. The highwalls were each examined as closely as safety rules would permit, both with and without binoculars. No evidence of a fossil vertebrate was discovered. With the aid of binoculars it should have been possible to detect some fossils less than one

inch in diameter, depending upon shape, color, angle of exposure, etc. Careful examination of numerous spoil piles by as many as eight workers yielded but few vertebrate fossils. These include several teleost fish scales and a few turtle shell fragments representing the genus, Adocus. One and one-half days were spent screening the different lithologic units exposed in the mine. The screening was done in ponds on the mine property, as per the method explained under fossil collecting procedures.

As permits were obtained, several vertebrate sites were collected by surface pick-up, plaster jacketing of specimens and by screen washing. These sites all showed evidence of small vertebrates at the surface. An additional site was screen washed which did not show any surface evidence of them (Section 18, T22N, R9W; Kimbeto Quad.). This was the only site which with screening did not yield small vertebrate fossils.

Samples were taken for screening such that not more than one cubic meter was taken from any given spot. This limit for matrix removal was also followed with the dinosaur material taken in plaster jackets.

It was observed that weathering proceeds rapidly on any exposed vertebrate fossils, but it apparently affects larger bones, especially in clayey matrix, the quickest. Therefore, bones should be removed as soon as possible after discovery. If it becomes necessary to delay collecting for several months, large specimens should be coated with a sealing agent, covered with plastic or paper and buried.

Time-Cost Study for Fossil Vertebrate Collecting

Two vertebrate fossil sites were collected for exposed dinosaur specimens and seven were collected for small vertebrates by screen washing. This was done in addition to the specimens that were collected in the San Juan Mine near

Farmington. Time recorded is just for actual collection of fossils and does not include time used to study lithology, take notes or pictures.

Site: San Juan coal mine, Yucca, Pit.

Formation: Fruitland.

Lithology: Claystone, shale, siltstone, sandstone and coal.

Occurrence: Fossils were only recovered from clay-shale units in the spoil piles as surface pick-up.

Identification: Several teleost fish scales and the anterior part of a turtle plastron; genus, Adocus.

Time/Cost: Four men each working ten and one-half hours = 42 man hours.

Site: San Juan coal mine, Yucca Pit.

Formation: Fruitland.

Lithology: Claystone, shale, siltstone, sandstone and coal.

Occurrence: Fossils were only recovered from clay-shale units in the spoil piles by screen washing.

Identification: Several teleost fish scales and a crocodilian tooth.

Time/Cost: Three men each working eleven hours = 33 man hours.

Site: Kimbeto quadrangle; Sec. 9, T22N, R9W.

Formation: Kirtland.

Lithology: Tan shale containing carbonized plant matter.

Occurrence: Moderately large dinosaur pelvis, incomplete, fragmented and partially weathered. Collected in a plaster jacket.

Identification: Hadrosaurian dinosaur.

Time/Cost: Three men each working eight hours = 24 man hours.

Site: Kimbeto quadrangle; Sec. 18, T22N, R9W.

Formations: Kirtland.

Lithology: Yellowish-brown silty sandstone to sandy siltstone.

Occurrence: Partial skull, badly weathered on exposed surface, with incomplete dentition. Four isolated caudal vertebrae found as float 40 feet to west. Skull collected in a plaster jacket.

Identification: cf. Kritosaurus (hadrosaurian dinosaur).

Time/Cost: Three men each working 14 hours = 42 man hours.

Site: Kimbeto quadrangle; Sec. 18, T22N, R9W.

Formation: Kirtland.

Lithology: Yellowish-brown sandy siltstone.

Occurrence: Ten bags of sediment (about 70 pounds per bag) were taken from the dinosaur skull site above and screened. No small vertebrates were seen on the surface.

Identification: No small vertebrates were found, only small pieces of ?dinosaur bone.

Time/Cost: Two men each working eight hours = 16 man hours.

Site: Alamo Mesa West quadrangle; Sec. 33, T24N, R13W.

Formation: Kirtland.

Lithology: Channel sandstone and bentonitic shale.

Occurrence: Ten bags of weathered sandstone, and six bags of shale (about 70 pounds per bag) from this site were screened. Fairly numerous small vertebrates were exposed at the surface.

Identification: Nineteen teeth of an estuarine to fresh-water shark; 58 ray teeth, ?Myledaphys; 40 scales and one skull fragment of Lepisosteus (gar); 167 teleost fish teeth representing at least three taxa; 50 teeth of ?Paralbula (teleost fish);

four turtle shell fragments of cf. Trionyx; 112 complete and incomplete small crocodilian teeth; 18 broken coelurosaur dinosaur teeth; 2 ? Dromaeosaurus teeth (coelurosaurian dinosaur); 1 ? Paranychodon tooth (coelurosaurian dinosaur); 3 well-worn hadrosaur teeth, numerous hadrosaur and/or ceratopsian tooth fragments; 3 ceratopsian teeth; 1 ?Stegoceras (ornithopod) tooth; several teeth of multituberculate mammals, cf. Meniscoessus (4 cheek teeth, nearly complete to complete), ? Mesodma (1 cheek tooth), ? Essonodon (3 incomplete teeth), ? Catopsalis (1 cheek tooth), 10 unidentified broken multituberculate teeth.

Time/Cost : Three men each working five hours and two men each working 34 hours = 87 man hours.

Site: Alamo Mesa West quadrangle; sec. 33, T24N, R13W.

Formation: Fruitland.

Lithology: Gray-green shaley siltstone, highly organic.

Occurrence: Ten bags (70 pounds per bag) of weathered and unweathered matrix were screened. Small vertebrates exposed at surface.

Identification: Fifteen teeth of an estuarine to fresh-water shark; 5 ray teeth, ?Myledaphus; about 90 scales and 1 tooth of Lepisosteus (gar); about 250 teleost fish teeth representing at least 3 taxa; 26 teeth of ?Paralbula (teleost fish); 6 baenid turtle shell fragments; 5 trionychid turtle shell fragments;

26 cf. Adocus shell fragments; 23 complete and incomplete small crocodilian teeth; 1 incomplete multituberculate incisor.

Time/Cost: Two men each working 32 hours = 64 man hours.

Site: Alamo Mesa West quadrangle; Sec. 34, T24N, R13W.

Formation: Fruitland.

Lithology: Carbonaceous shale.

Occurrence: One 70 pound bag of sediment was screened. Small vertebrate fragments exposed at the surface.

Identification: Two teeth of an estuarine or fresh-water shark; 2 ray teeth, ?Myledaphus; 25 Lepisosteus (gar) scales; 35 teleost fish teeth representing at least two taxa; 5 baenid turtle shell fragments; 13 cf. Adocus shell fragments; 3 crocodilian teeth.

Time/Cost: Two men each working 12 hours = 24 man hours.

Site: Alamo Mesa West quadrangle; Sec. 33, T24N, R13W.

Formation: Fruitland.

Lithology: Carbonaceous shale.

Occurrence: One 70 pound bag of sediment was screened. Small vertebrate fragments exposed at the surface.

Identification: About 50 teeth of an estuarine or fresh-water shark; 14 ray teeth, ?Myledaphus; 1 Ischyrhiza (sawfish) tooth; 37 scales and 3 teeth of Leipsosteus (gar); over 100 teleost fish teeth representing at least three taxa; 10 teeth of ?Paralbula (teleost fish); 1 multituberculate incisor.

Time/Cost: Two men each working 28 hours = 56 man hours.

Site:	Alamo Mesa West quadrangle; sec. 33, T24N, R13W.
Formation:	Fruitland.
Lithology:	Carbonaceous shale.
Occurrence:	Six bags (70 pounds per bag) of weathered and unweathered sediment.
Identification:	One ray tooth, ?Myledaphus; 3 scales and 1 tooth of Lepisosteus (gar); 37 teleost fish teeth, at least two different taxa; 11 ?Paralbula (teleost fish); 14 cf. Adocus shell fragments; 2 large crocodilian teeth.
Time/Cost:	Two men each working 8 hours = 16 man hours.

Site:	Kimbeto quadrangle; Sec. 35, T23N, R9W.
Formation:	Nacimiento.
Lithology:	Brown silty shale.
Occurrence:	Ten bags (70 pounds per bag) of weathered and unweathered sediment.
Identification:	One lower premolar of ?Mesodma (multituberculate); 4 mammalian tooth fragments.
Time/Cost:	Two men each working 11 hours = 22 man hours.

In addition to the present salvage done and the resulting time/cost figures for recovering specimens, other data were obtained from paleontolgists who have worked the San Juan Basin. A number of years ago the University of Kansas began collecting fossil vertebrates in Cretaceous and Early Tertiary formations, mostly by screening, in the Bisti and Kutz Canyon areas. This work continued for five summers with approximately six weeks being spent collecting each summer.

A little more than half the time was spent working the Cretaceous deposits. Approximately 500 identifiable vertebrate specimens, mostly mammalian teeth, were recovered. Although less than half the time was spent collecting in the Early Tertiary deposits, the yield was many times greater. Usually five persons comprised the field crews, so about 550 man days were spent in total. The Museum of Northern Arizona collected a partial Kritosaurus skeleton from a sandy unit of the Fruitland Formation in the Pretty Rock Quadrangle area. This material consisted of a partial quadrate, a humerus, a moderate section of vertebral column with some ribs, an incomplete pelvis, a femur and a few unidentified bone fragments. It took three men eight working days to collect this material, making a total of 24 man days. Five people from the above museum spent a total of 13 man days collecting several associated ? Alamosaurus bones from the base of the Ojo Alamo Formation in the Alamo Mesa east quadrangle. The bones included two vertebrae, an ilium and parts of limb bones.

The reports by Kues et al. (1977, 1978) and accompanying records submitted to the Bureau of Land Management in Albuquerque, New Mexico, provide additional data concerning fossils collected over wide areas within the San Juan Basin.

Invertebrates

Invertebrate fossils studied in Bureau of Land Management permitted areas near Farmington, New Mexico are represented mainly by fresh water bivalves with few gastropods. They generally occur in thin lenses of siltstone within stable units. The fossil horizons approximate a few inches in thickness up to a hundred or more feet horizontally.

Three areas were collected, one at the Bisti Badlands, and two near the fossil forest, or standing stump area. At each of the three sites, surface collecting of all reasonably preserved specimens was supplemented with a cubic meter of excavation to expose additional fossils.

In most cases surface and excavated specimens of bivalves and gastropods were rather strongly decalcified due to in situ weathering. This made the fossils extremely friable and in many cases changed their outer surface to a powdery condition, this at the expense of external details in shell ornamentation. By collecting essentially all reasonably complete specimens, without regard to duplication of taxa, good collections were made which document the available fossil record for these sites. In the salvage operation of invertebrate fossil sequences, it seems best to collect all reasonably preserved specimens while the opportunity exists. Any form of restrictive selection in sample size presupposes at least some degree of definitive understanding of the fauna in terms of taxonomy and intraspecific variability. This supposition seems unwarranted in light of the restricted number and size of invertebrate sites. It seems far better to make complete collections prior to the cataclysmic stratigraphic disturbance anticipated by area surface mining. Collections can be thinned later by qualified researchers if such thinning is necessary because of storage limitations. This is a decision which much be made very carefully, because after mining there is

no possibility for supplementary collecting. This fact was made clear as we tried to tie fossil molluscs collected in spoil piles with the stratigraphy exposed in an adjacent highwall. It could not be done with high accuracy, which rendered the specimens of limited value.

Specimens once collected were cleaned of adhering sediment with hammer and chisel. Fossils forming coquina-like layers were soaked overnight in water to free the fossils from their silty clay matrix. This process did disaggregate the material, but unfortunately, it did the same to the fractured shells as well. Soaking apparently is of limited value, in at least some cases.

Time-Cost Study of Invertebrate Collections

Three sites were collected, with Bureau of Land Management permits for each. Two sites were near the standing stump area, and the third from the Bisti area. Records were also obtained for spoil pile collecting; however, because the collectors were seeking all types of fossils, data pertaining to invertebrates alone is approximate only.

Bisti Badlands, Site 1: Uppermost Fruitland Formation (< 50 feet from top of unit) (Sec. 24, T23N, R12W), Pretty Rock Quad.

Occurrence: Bivalves and gastropods were collected from a 6-1/2 - 12" bed which extends over an area of approximately 450 feet by 200 feet. It was observed in the field that larger and less ornamented specimens were generally collected closer to the margins of the site.

Lithology: Shale, silty with thin irregular interbedded channel sands.

Collections: Total of specimens collected - 379, of which 117 were reasonably complete. This includes surface collecting and a one cubic meter excavation.

Time/Cost: Seventy-six specimens per man hour (379 specimens collected by five men in 60 minutes).

Bisti Badlands, Site 2: Uppermost Fruitland Formation (< 50 feet from top of formation Sec. 23, T23N, R12W, Pretty Rock Quad.

Occurrence: Bivalves and gastropods were collected from two 2-3" layers. Specimens were often fragmental, others were well preserved and entire.

Lithology: Silty shale with channel sands.

Collections: Total specimens collected - 288, of which 44 were reasonably entire. Collections include surface pickup and approximately one cubic meter of excavation.

Time/Cost: By extrapolation, 144 specimens per man hour (288 specimens were collected by two men in one hour).

Bisti Badlands, Site 3: Upper Fruitland Formation near Bisti trading post. Sec. 33, T24N, R13W, Alamo Mesa West Quad.

Occurrence: Bivalves and rare gastropods were collected at the surface as well as in a total of one cubic meter of excavation.

Lithology: Silty carbonaceous shale with sand interbedded throughout. Fossils were collected from shale units.

Collections: Approximately 200 specimens including both reasonably well preserved material and usable fragments.

Time/Cost: Approximately 35 usable specimens per man hour (approximately 200 specimens were collected by three men in two hours).

Yucca Pit, San Juan Mine, Western Coal, Farmington, New Mexico.

Occurrence: Bivalves and fewer gastropods were collected from three week old spoil piles. Specimens were in reasonably good shape, although some decalcification was apparent.

Lithology: Shales, air slacked and friable with some calcareous concretionary masses containing the mollusc fossils.

Collections: Approximately 100 reasonably complete specimens were collected.

Time/Cost: A total of 100 man hours was spent searching through the spoil piles at Western Coal Co.'s San Juan Mine. Fragmentary material of both plant and invertebrates was abundant, but often so poorly preserved as to make recovery impossible. If all effort is charged to the invertebrates, the result is approximately 1 specimen per man hours, although where invertebrate material was reasonably abundant locally, the ratio would approximate 20 specimens per man hour as an estimation.

RECOMMENDATIONS FOR MITIGATION

Direct Impact

After studying many mining operations, some in detail, one fact became abundantly clear: that even under the best of conditions the fossil collections made in mines would be very incomplete and highly biased. Fossils occurring in rock units with a high clay content would be recovered from spoil piles in a disproportionately low ratio compared to those in rock units with a low or no clay content. Fossils collected from the mining highwall would be limited to a great extent by safety considerations. Those picked up in the dragline bucket would usually be considerably broken. In view of the many limitations inherent in fossil salvage operations within mines, it is our opinion that the most meaningful salvage must be accomplished in areas of direct impact well before mining operations commence there. However, this is not to say that we consider the need to collect fossils in the mines unimportant. Despite limitations, collecting in the mines will produce significant fossil materials.

It appears advisable to initially hire more paleontological field workers than would be needed later, in order to adequately salvage areas where new mining operations are imminent. Then as fossil salvage operations moved sufficiently ahead of areas being mined, fewer personnel would be needed. Those employed should proceed well ahead of the areas to be mined, carefully salvaging fossils from all exposures containing them. This should probably be done at least two years in advance of the schedule for the initial mining operation of that particular area. The reason for this much lead time is as a safeguard to insure that all important fossil materials can be collected. As is often the case, when fossils are prepared and identified some specimen or

specimens are found to be unique and/or exceptionally important. It would then be desirable to go back and collect more material if at all possible. This would be especially applicable to specimens recovered through screen washing; and since screen washing is a relatively slow process (some areas have been screened for many years and still yield important fossils), a two-year lead time is not too much. Cretaceous mammals are both rare and scientifically very important. Most are of very small size. Teeth, which are the most commonly used means of identifying these mammals, are sometimes so small as to pass through a screen with 1 mm squares. A smaller mesh is needed to obtain these. Unfortunately the sediment in which many mammals occur in the San Juan Basin has a high clay content and will load screens of very fine mesh (e.g., 0.5 mm squares). In order to pass this sediment through the finer mesh screen, it must first be agitated in a water solution containing commercial detergent for a period of 12 to 24 hours. Obviously salvage operations would be slowed considerably to facilitate this type of collecting.

Our study has led us to the conclusion that a most critical time in the overall salvage operation is when a new area is prepared for surface mining. One of the preliminary steps involves bulldozing of the soil and vegetation. This would be an ideal time for a paleontological field crew to become involved in an intensive collecting operation. Unweathered rock which still retains its stratigraphic integrity will be exposed over a widespread area. By working closely with equipment operators, more complete collecting could be accomplished. It would be important to have very accurately located and recorded the fossil finds that occurred in the earlier salvage operation of the area. This is necessary so that the equipment operator can be carefully guided at these sites and that a sufficient number of paleontological field workers can be on hand for recovery.

Indirect Impact

It is our recommendation that the fossil salvage operation be extended to include all areas where fossiliferous strata are known to occur in the vicinity of present or proposed coal mining operations. The purpose of this is to protect fossils from anticipated indirect impacts. Presently, unauthorized fossil collecting is taking place in the San Juan Basin on a significant scale. Local rock shops for example have San Juan Basin fossils for sale and private collectors have accumulated them for many years. Additionally, spot checking in residential as well as commercial properties in Farmington and surrounding communities showed that many people used fossil logs in landscaping (see Pl. 12, 13). Some were so large that heavy equipment must have been used in extracting and transporting them. The certain major increase in coal production in the San Juan Basin will create a local population explosion. This will undoubtedly greatly increase the amount of unauthorized fossil collecting in the area, as many people pursue the hobby of rock-hounding. Also, the increased population will mean new roads, new gas and water pipelines, new powerlines, etc., all of which present the potential of adversely impacting fossils.

Although the anticipated increased numbers of people who would be pursuing hobbies of rock-hounding or other amateur collectors that would seek fossils could pose a serious problem, they could possibly be made a part of the solution. Present programs in various places have shown that these people are capable of working with professional paleontologists in both collecting and curating when properly trained. These people could be used as volunteers in the proposed fossil salvage operation, thereby reducing the costs involved.

PROPOSED METHODS FOR COLLECTING

Area Surface Mines

Mitigation in the strip mines necessitates somewhat unorthodox fossil collecting techniques. In stepwall mining where more than one coal seam is involved, the strata exposed on the step above each seam should be searched for fossils. Those with a wall of eight feet or less in height could be collected manually. Those above eight feet and below twenty could be mechanically collected with a front-end loader. The walls above twenty feet would have to be collected with the dragline.

Since close examination of the highwall is contrary to established mine safety laws, this surface has to be inspected from a distance. This was accomplished by standing and studying the highwall through binoculars, thus determining if any fossils, particuarly vertebrates, were exposed (Pl. 6b). In using this method, we observed a plant horizon and a bed containing an abundance of invertebrates, some of which were collected (Pl. 5a, 6a, 6b). The highwall should be monitored periodically for fossils which may have become exposed during dragline operations. Any significant fossil materials would be tagged for future collecting by the dragline. During the operation the bucket containing this material would be placed upon the highwall pad. This rock debris would afterwards be spread out by bulldozer or front-end loader to better expose fossil material for collecting.

The pad of the highwall is drilled at regular intervals (5" to 14" diameter holes at approximately 15 to 20' centers) in preparation for blasting the overburden (Pl. 2d). In the process of loosening this overburden, the detonation would invariably break up any large fossils present below the pad surface. A means of reducing this happening is by studying the cuttings from these holes

prior to loading with explosive for any traces of underlying fossils (Pl. 2c, 2e). The shot hole adjacent to the fossil at least could be filled with sand. The explosion would thus, be restricted to an area above and below the fossil protecting it from disintegration. This procedure would protect the rock, and consequently the fossil, from breaking up when the shot is fired. The fossil, when later exposed in the highwall, could then be collected by the dragline. Although this procedure was not tried, because of scheduling and coordination problems, miners with whom the idea was discussed considered it feasible.

During the salvage operation fossiliferous horizons will be located. Then, during the preparation of the pad for the dragline, these horizons could be exposed by the dozer as it scrapes away the surface layers. Since this preparation proceeds the dragline operation by a considerable interval of time, collections could be made from these fossiliferous zones without interrupting the normal mining sequence. In this way much of the mitigation could be accomplished before the materials are moved to the spoil piles.

Spoil Piles

Collecting fossils from spoil piles that result from mining operations will never be ideal for several reasons: 1) Only a small part of the total volume of rock in the piles is exposed. 2) The displacement of rock, and hence any contained fossils, disrupts the integrity of the original stragigraphic position. 3) Collection of fossils is made difficult by the steepness (33° - 34° slope) and instability of each pile. 4) The rapidity with which spoil piles accumulate would necessitate many man hours in order to do a thorough job. 5) For safety reasons the approximately three-week delay from the time the spoil pile is formed until it can be inspected, allows for significant deterioration of exposed fossils. Despite these obvious disadvantages, we feel that attempts to salvage fossils from spoil piles should be made. The

total numbers of fossils that will be destroyed in coal mining operations (and the loss of scientific data which they could have provided) is staggering. Much of this "lost" material will be in the spoil piles. Therefore, a careful, and in some ways unique, fossil collecting program should be conducted to mitigate this loss.

We recommend that when spoil piles are searched for fossils that this be done systematically by at least two people (the chance of injury is higher than usual in this type of collecting and individual safety must be considered). Spoil piles should be collected as quickly as it is safe to do so after they are formed in order that the exposed fossils will not deteriorate unnecessarily. Various preserving agents, depending upon the type and condition of the fossil involved, could be employed to advantage in many instances. Most of the fossils we found were in a clayey matrix which expanded significantly with only short exposure to the air causing concomitant damage to contained fossils.

Our observations indicate that as people spend more time in a mine they become increasingly familiar with even minor changes in stratigraphy and lithology. This is invaluable in preserving as much data as possible in the collecting process. In the San Juan Mine the lithology of the Fruitland Formation is sufficiently varied to be able to identify rock in spoil piles to within three feet of their original stratigraphic position in some cases; and in most others to no more than 15 feet. The dragline used in this mine operates in approximately a 600 foot radius. This means that in the operational procedure now being followed that a spoil pile would be no more than about 600 feet from the spot it was excavated. Depending upon how the dragline operator worked, it might be possible to determine where rocks on the spoil pile were originally located to within a 150 foot square area on the horizontal plane. It then should be possible in most instances to have enough vertical and horizontal

control on collected fossils to make them scientifically valuable. To maximize the recovery of important data, detailed notes must be kept by persons doing the collecting, including mapping the original position of the fossils as accurately as possible.

It is further recommended that special attention be paid to locating clasts on the spoil pile which contain small vertebrates. If one is found, lithologically similar clasts in the area should be collected for screen washing, assuming they too would be productive.

Underground Mines

Mitigation of fossils in an underground mining situation is very difficult. Fossils within the coal are usually crushed, washed and conveyed as part of the coal processing without ever being observed. Therefore, the most likely fossils to be collected or studied are those in the mine roofs or associated with the coals outside of the actual mining operation. Two problems, however, are encountered when studying fossils in mine roofs. The first is due to the lime and roof plates that are used. The rock dust, as required by law, coats the floors, walls, and roofs of the mines so that nothing but lime can be observed. Thus, the only time that fossils can be seen is when the lime is removed. This removal usually occurs as the roof begins to collapse, exposing the fossils. This leads to the second problem, that of safety. When the roof begins to collapse, that portion of the mine is unsafe. In the continuous mining method currently employed, the pillars are removed as the machinery is moved backward, leaving an extremely hazardous situation. This was observed in the York Canyon Mine near Raton. As the pillars were removed, the roof began collapsing almost immediately. The cracking and crashing of the roof with large amounts of subsequent dust would prohibit fossil collecting.

In older portions of underground mines, where timbers were used and are still sound, the roof is more or less stabilized, fossils could be studied, but again their collecting would be hazardous. It is virtually impossible to remove fossils from the roof safely. Those on the floor can be collected, but because these are from rocks once attached to the roof, fossil removal must be done rapidly before more caves in.

Two possibilities for successful mitigation would be, first, training miners in fossil recognition. They are most likely to see any fossils that are present. They could be trained in collecting techniques for safe removal of the fossil materials where possible and as to whom to notify when something is found. The second would be salvage and/or study of the fossil materials before mining begins. A study could be initiated that is contemporaneous with the mining operation, but generally outside of the mine. From our observations, the latter holds the most promise.

PALEONTOLOGY MONITORING SPECIALIST

It is the recommendation of the writers that implementation of mitigation procedures require the constant monitoring of a trained paleontologist. It would be the responsibility of the paleontologist to continually monitor all mining operations within a designated area, in the San Juan Basin, to identify and supervise the recovery of any paleontological deposit encountered in the process of site preparation, overburden removal and coal excavation. It would also be to his great advantage to informally educate mine personnel concerning expected kinds of fossils and the occurrences which may be encountered in various phases of mining.

This person should be a trained professional (Master's degree) with a specialty in paleontology or paleobotany able to deal with the known variability and techniques of vertebrate, invertebrate and plant fossils that exist in the San Juan Basin. The need for a generalist in paleontology with significant field experience seems essential for the successful mitigation of the abundant and varied fossil fauna and flora which exists in the area. This person would likely require a field assistant to help with collecting, tagging, etc. as well as for safety precaution.

Supervision of the monitoring specialist would best be accomplished by the same governmental agency which will supervise the mining operations. The highly trained professional staff of the U.S. Geological Survey could be utilized for the purpose of supervision, etc.

In our assessment of the mining operations presently underway in the basin, it is our opinion that two such monitoring specialists would be required in order to keep up with day by day changes in the mines. Current coal mining operations are centered around Gallup and Farmington, New Mexico. These two areas are sufficiently separated that a single monitor would be unable to provide the needed control in both areas.

These monitors will need trained collecting crews at times, as indicated above in this report.

Collecting fossils in the mines will require the assistance of mine personnel. Subsequent to the discovery of a valuable fossil deposit the paleontologist could mark the deposit in some manner, such as flagging it, then supervise the recovery of the material. If the fossils were in the highwall which would necessitate the use of a dragline for collection, the monitor could communicate with the operator by radio, or directly while riding in the control room of the dragline.

Need for Cooperation

The success of mitigating paleontological resources in the path of massive strip-mining operations will be successful only to the extent that a cooperative working relationship exists between mining, government and academic interests. If an attitude of mutual support can be established by the persons representing these interests, then methods and procedures of fossil collecting will develop as requirements warrant. This will enable the recovery of coal in an orderly and cost efficient manner while the fossils are being recovered and saved for their unique value. If animosity develops, miners can all too easily frustrate the mitigation efforts. This would be especially true in underground mining operations.

CONCLUSIONS

The following points are concluded from our study of the mining operations, of fossil occurrences, and of possible mitigation procedures.

1. The San Juan Basin holds an enormous deposit of valuable coal. This resource is vital to the nation's energy requirements.
2. Within the basin is preserved a flora and fauna of wide variety and distribution, representing Late Cretaceous and Early Tertiary continental and lacustrine life.
3. This fossil reserve is also a valuable national resource which requires careful conservation measures.
4. Because of the catastrophic disturbance to the overburden, all fossils of value should be removed prior to the mining operation.
5. Salvage efforts, prior to mining operations, will return the greatest number of fossils, and a thorough salvage program will be the most useful part of any mitigating effort.
6. Fossil recovery concurrent with mining will be collections of opportunity.
7. Problems of discovery, timing and coordination with mining operations severely limit fossil collection.
8. There exists a need for constant observation by a trained paleobiologist to insure the preservation of a meaningful sample of the fossils present.
9. The key to a successful coordinated mining program and fossil collecting effort will be cooperation by all involved parties. Fossil collecting and mining can be compatible if there exists a mutually cooperative atmosphere. It is vital that the paleobiological monitor selected be a person who relates well with people.

10. Education of mine personnel to the need of preservation of fossils in our public lands and the inherent value of these fossils in understanding the earth on which we live will enhance the success of any mitigating effort on the part of the Bureau of Land Management.

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Plate 1

a. Area surface mining at San Juan Mine, Farmington, New Mexico. Highwall pad on right, coal exposed in center with overburden removed, and spoil piles on left. Drilling machine for drilling overburden is shown in the background.

b. Stepped highwall at Carbon Coal Co., Gallup, New Mexico. Upper wall is approximately 20 feet high.

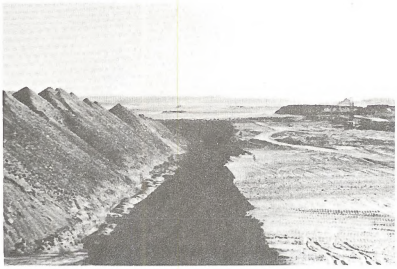
c. Dragline removing overburden at San Juan Mine, Farmington, New Mexico. Exposed coal can be seen at lower left.

d. Stepped highwall where multiple seams of coal are removed. Carbon Coal Co., Gallup, New Mexico.

e. Pit after coal is removed. Unmined rock to right, spoil piles to left. San Juan Mine, Farmington, New Mexico.

f. Coal seam exposed during drilling of coal prior to blasting. Spoil piles in background. San Juan Mine, Farmington, New Mexico.

Plate 1



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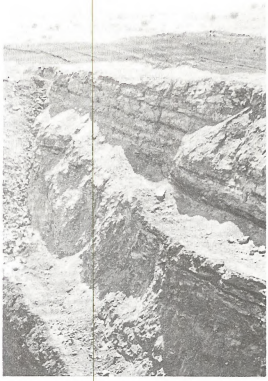

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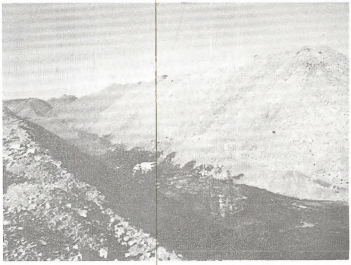

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Plate 2

a. Highwall at San Juan Mine, Farmington, New Mexico. Coal seam is exposed at base of highwall. Highwall approximately 50 feet high at this site.

b. Spoil piles prior to leveling for reclamation. San Juan Mine, Farmington, New Mexico.

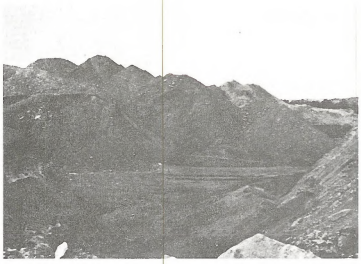
c. Cuttings from drill hole of overburden prior to blasting. San Juan Mine, Farmington, New Mexico. Largest fragments in pile are approximately one and one-half inch.

d. Drilling machine for drilling shot holes prior to shooting overburden.

e. Overburden area drilled, loaded and ready for blasting.

Plate 2

a



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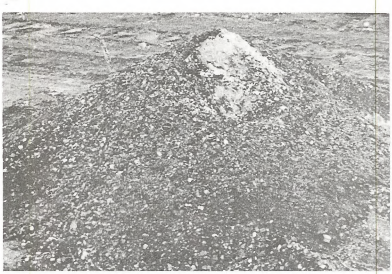

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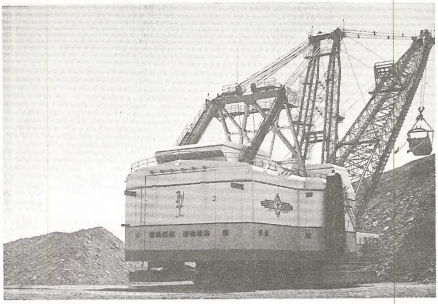
Plate 3

a. Dragline removing overburden at San Juan Mine, Farmington, New Mexico.

b. Spoil pile close-up at San Juan Mine, Farmington, New Mexico. Largest boulders in foreground are approximately 6-4 feet across.

c. Stabilizing spoil piles.

Plate 3



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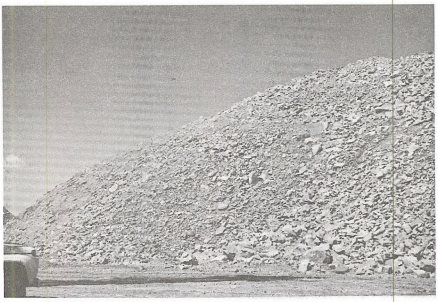

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Plate 4

a. Plaster jacketing a dinosaur bone in the field prior to removal to lab for study. Along Betonnie Tsosie Wash. Bisti badlands, San Juan Basin, New Mexico.

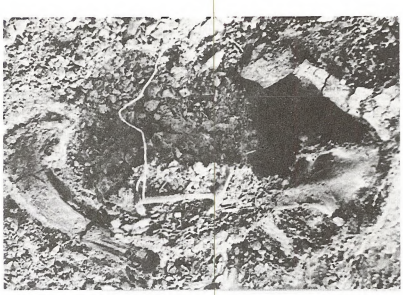
b. Dinosaur fossil exposed at surface prior to plaster jacketing and removal. Along Betonnie Tsosie Wash, Bisti badlands, San Juan Basin, New Mexico.

c. Dinosaur bones plaster jacketed and ready for transport to lab for study. Along Betonni Tsosi Wash, Bisti badlands, San Juan Basin, New Mexico.

d. Collecting material for screening process to recover small bones and fragments from Fruitland Formation. Along Betonni Tsosie Wash, Bisti badlands, San Juan Basin, New Mexico.

Plate 4

a



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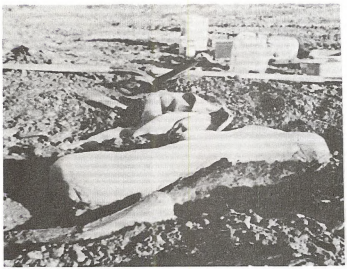

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Plate 5

a. Arrows indicate carbonized leaf fragments in highwall (Fruitland Formation) at San Juan Mine, Farmington, New Mexico.

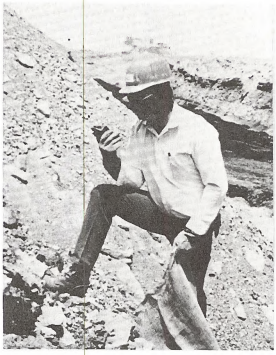
b. Collecting material from spoil pile for subsequent screenting. Yucca Pit, San Juan Mine, Farmington, New Mexico.

c. Highwall showing area of figure a in perspective of entire face approximately 100 feet high. Close up (fig. a) is approximately in upper center of photograph.

d. Collecting plant and vertebrate fossils from spoil piles at Yucca Pit San Juan Mine, Farmington, New Mexico.

Plate 5

a



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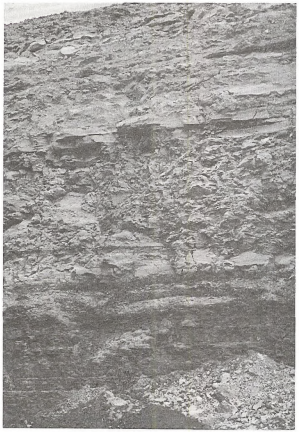


c

d

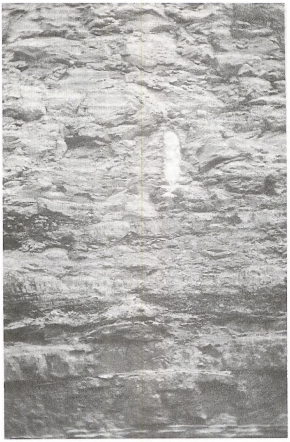
Plate 6

a. Closeup of fossil plant exposed approximately 35 feet above base of highwall (Fruitland Formation) at San Juan Mine, Farmington, New Mexico.

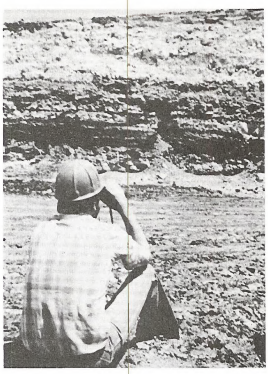
b. Worker viewing highwall with binoculars for possible occurrence of fossil material.

c. Highwall showing plant fossil at San Juan Mine (see a. above).

Plate 6



a



b

c

Plate 7

a. Washing potential fossiliferous sediment through screens for concentration and further examination. Bisti badlands, San Juan Mine, Farmington, New Mexico.

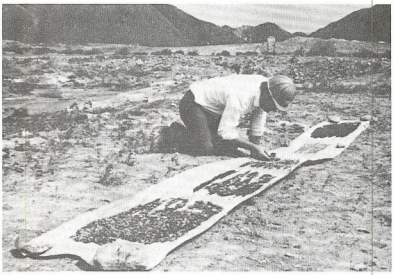
b. Examination of washed and screened residue of Fruitland Formation, San Juan Mine, Farmington, New Mexico.

c. Close up of figure b above.

Plate 7

a

b



c

Plate 8

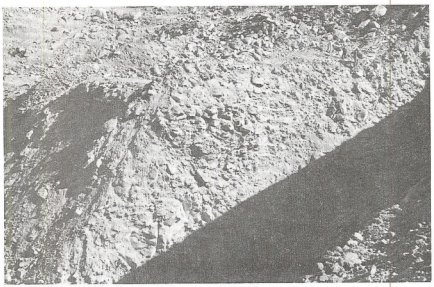
a. Workers painting test specimens in overburden deposit at San Juan Mine, Farmington, New Mexico.

b. Site of test specimen preparation prior to removal by dragline. Test specimens simulate fossils discovered and marked for removal.

c. Area of spoil pile in which one bucket (63 cubic yards) of test and other rock was dropped by dragline. Colored rocks were totally buried by the rock debris from the bucket.

Plate 8

a



b

c

Plate 9

(all photos of San Juan Mine, Farmington, New Mexico)

a. View from dragline operator's perspective. Highwall on left, spoil piles on right.

b. Dragline bucket collecting painted rocks for test of recovery.

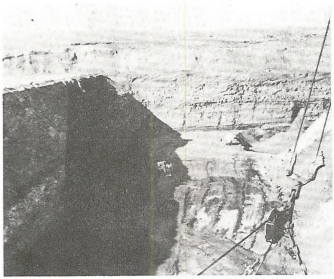
c. Dragline bucket filled with painted rocks in collection test operation.

d. Loaded dragline bucket containing painted rocks as part of collection test.

e. Dragline about to drop test specimens on pad.

f. Detail showing manner in which large flat painted test specimens ended up on top of bucket-load (63 cubic yards).

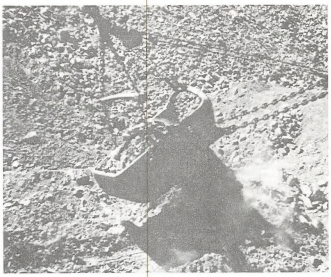
Plate 9



a

b

c



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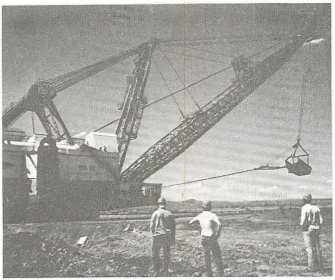

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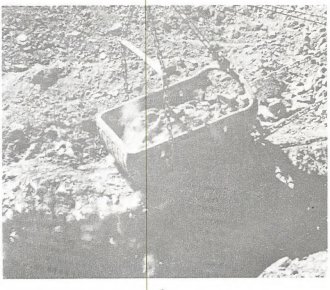


f

Plate 10

a. Test specimens of painted rock being removed from pit at San Juan Mine.

b. Pile of test specimens on pad at San Juan Mine.

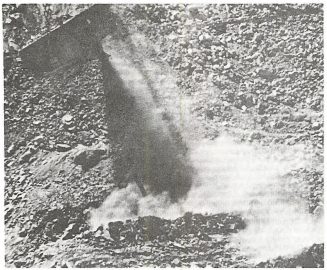
c. Pile of test specimens after spreading by bulldozer.

d. Test specimens being spread by bulldozer.

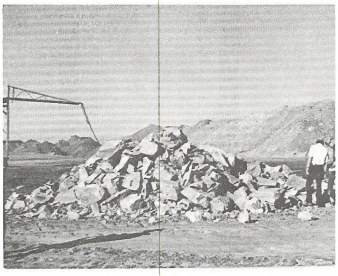
e. Test specimens being spread by bulldozer. Largest specimens approximately five feet across.

f. Searching for colored surfaces of test specimens after removal and spreading.

Plate 10



a



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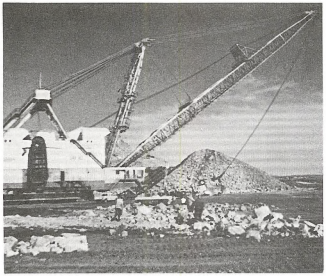


c

d

e

f

Plate 11

Typical sequence of overburden removal
by 63 cubic yard dragline at
San Juan Mine, Farmington, New Mexico.

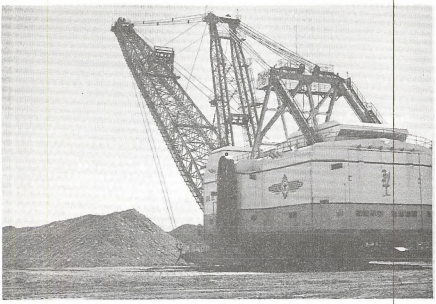
a. Return of empty bucket from previous swing.

b. Filling bucket with overburden material exposing the coal at base of cut.

c. Dumping bucket of overburden on spoil pile.

Plate 11

a



b

c

Plate 12

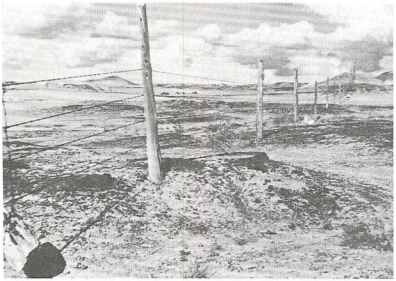
a. Fossil wood used to secure government fence in Bisti badlands, San Juan Basin, New Mexico. Such uses are typical of indirect impact on fossils.

b. Detail of figure a. above.

c. Fossil logs used in private landscaping, Farmington, New Mexico.

d. Detail of figure c. above.

Plate 12



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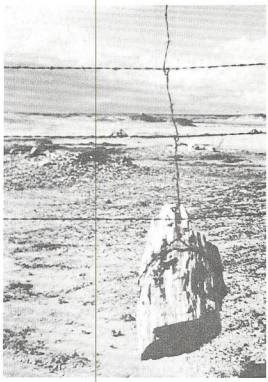

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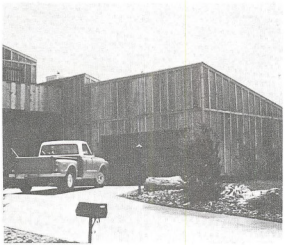

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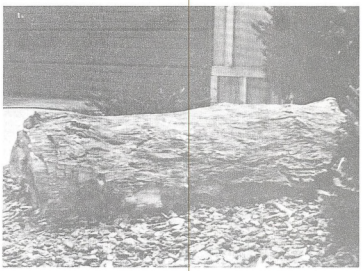


d

Plate 13

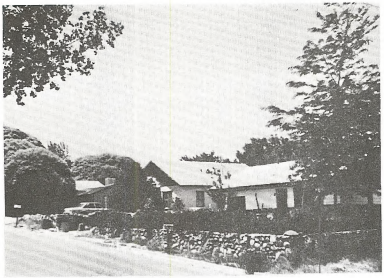
a. Rock fence with fossil "fence posts," Farmington, New Mexico. For example of indirect impact on fossils.

b. Detail of figure a above.

c. Fossil log decorating downtown business office. An example of indirect impact on fossils.

d. Detail of figure c above.

Plate 13



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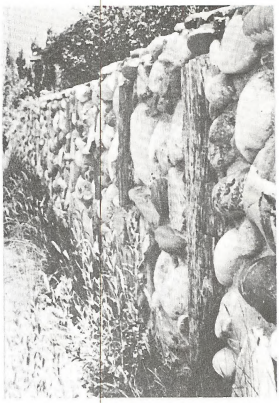

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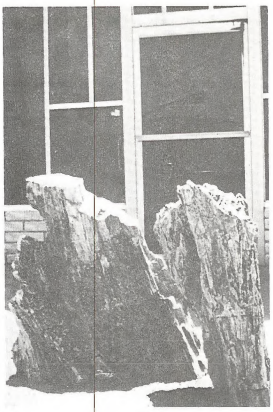

d

IN REPLY REFER TO

1513

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
3550 Pan American Freeway, N.E.
P.O. Box 6770
Albuquerque, New Mexico 87107

MAR 28 1979

Dr. Wade Miller
Department of Geology
Brigham Young University
Provo, Utah 84602

Dear Dr. Wade:

Dr. J. Keith Rigby, Jr. of our staff has informed me that the submitted draft annotated bibliography compiled under BLM contract YA-512-CT8-250 is of acceptable quality. Dr. Rigby also informs me that he has suggested at least one other reference to include in the bibliography. We trust that during the life of the contract, until final preparation of the report, that as additional references come to your attention, that these will also be added to the bibliography.

Dr. Rigby also has informed me that you would like some clarification as to priorities under which the remaining work should take place. Our prime concern is to document the feasibility and utility of salvage or mitigation techniques to be used in a coal mining context. We offer for your consideration the following set of priorities:

1. Prove the salvage feasibility of various sorts of fossil materials in areas of direct impact.

2. Estimate the costs of such techniques.

3. Prove the feasibility of mitigation for anticipated indirect impacts.

4. Estimate the costs of such indirect impact mitigation.

In this context, we would identify the following areas as being of primary concern:

1. The Bisti Badlands, including the badlands along the exposures of the Kirtland and Fruitland formations along Hunter's, De-Na-Zin, Alamo and Willow Washes.

2. Similar stratigraphic intervals near Star Lake, New Mexico.

Areas of secondary concern would include areas of anticipated strong secondary impact:

1. Nacimiento exposures along De-Na-Zin, Kimbeto, Betonnie Tsosie, Escarbada and Torrejon Washes, Kutz Canyon and Bohannon Canyon.

We are also currently in the process of designating an appropriate site to conduct wet screening activities. Such a determination has not yet been made, but it is anticipated that the environmental processing for such a site will be completed during the first part of May, 1979. This decision will be made by our Farmington Resource Area staff. If you have further questions regarding this matter, please contact Mr. Bob Calkins, Area Manager, at (505) 325-3581 in Farmington.

We have also received communication from Mike College regarding the use of Mr. R. R. Usery in the coming summer project. A number of questions regarding conflict of interest have been raised and we are in the process of determining if there is in fact such a conflict. We will notify you of our findings as soon as our investigation is complete.

Mr. Sterling Grogan of Utah International, Inc. which operates the Navajo Mine southwest of Farmington was contacted by Dr. Barry Kues. We would suggest that you contact him on the results of his conversations with Mr. Grogan regarding the potential for excavating the dinosaur on their existing mine property.

We are awaiting your brief descriptions of proposed field excavations so that we may environmentally process the localities for such actions. We have enclosed a copy of the paleontological inventory that was done by U.T.E.P. for the Star Lake Mine. This enclosure should be copied, and we request the "original" be returned to us.

We wish you the best in your efforts of the coming field season.

Sincerely,

Gordon A. Frashier
Contracting Officer's Authorized Representative

Enclosure

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